BRUCE PEEL SPECIAL COLLECTIONS LIBRARY

UNIVERSITY OF ALBERTA LIBRARY

REQUEST FOR DUPLICATION

I wish a photocopy of the thesis by

____(author)

entitled____

The copy is for the sole purpose of private scholarly or scientific study and research. I will not reproduce, sell or distribute the copy I request, and I will not copy any substantial part of it in my own work without permission of the copyright owner. I understand that the Library performs the service of copying at my request, and I assume all copyright responsibility for the item requested.

Date	Name and address	Pages copied	Signature
JUL 22 1987	Canadian Hunter Exploration, Calg.	All	ILL-ML
AUG 25 1987	B.P. Canada, INC. Calgary	All	ILL-GM

THE UNIVERSITY OF ALBERTA

STRATIGRAPHY AND LITHOFACIES VARIATIONS OF THE UPPER CRETACEOUS SMOKY RIVER GROUP, GRANDE PRAIRIE REGION, ALBERTA

by

© MALCOLM S. ACHTMAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

FALL, 1972

ABSTRACT

The Smoky River Group mapped regionally in the Grande Prairie area includes the Cardium, Bad Heart, Doe Creek, and Chinook sandstones. The lithofacies of the Cardium Formation, interpreted from core, form a regressive sequence, grading bottom to top from open marine and lower shoreface shales and silty shales, to massive middle shoreface and tabular laminated upper shoreface sands, through to carbonaceous lagoonal or restricted bay mudstones, interrupted occasionally by cross-laminated channel sandstones. The distribution of these lithofacies is mapped using theoretical time lines between known time markers, including the First and Second White Specks. On a west-east stratigraphic cross section the Cardium and Bad Heart sands both remain roughly time line parallel, but on a SW - NE cross section these sands are strongly diachronous across the theoretical time lines.

Regional maps through time show that after the Grande Prairie region was inundated by a vast open marine sea, a NW - SE trending beach/barrier sandstone lithofacies of the Cardium migrated northeastward across the region. Then the area to the south underwent a period of non-deposition and/or the sediments were partially removed before the subsequent marine transgression of the Muskiki Formation. Later, the shoreline of another sandstone zone (Bad Heart), also trending NW - SE, migrated across much of the Grande

Prairie region.

Doe Creek sandstone deposition, the first Smoky River Group deposit associated with shallowing of the Kaskapau sea, migrated as a NW - SE trending zone from the SW to the NE. This zone of sandstone defines an approximate shoreline, the location of which is shown on one regional map.

The Chinook sandstone, last of the Smoky River Group sandstones (examined in core from only one well), is a regressive deposit similar to the Cardium and Bad Heart, and was deposited along the western edge of the map area.

ACKNOWLEDGMENTS

The author wishes to thank J. M. Park, Union Oil Company of Canada Ltd., Calgary, for suggesting the thesis topic and providing suggestions and criticisms as the work progressed. Thanks are due to Dr. J. F. Lerbekmo, University of Alberta, Edmonton, who supervised the study and critically reviewed the manuscript.

Special thanks go to J. E. Anderson, Union Oil Company of Canada, for his advice, particularly in regard to the part dealing with interpretation of Cardium lithofacies. C. F. Burk, Jr. provided subsurface information which assisted in making correlations.

Thanks are owing to the Oil and Gas Conservation Board, Alberta, for facilities for core examination and for permission to collect samples. Union Oil Company of Canada paid for core examination costs at the Conservation Board, supplied copies of all mechanical logs and base maps required, and provided the services of the drafting department for drafting of the final maps and cross sections as well as photocopying of the final text.

Financial assistance was provided by the University of Alberta in the form of graduate research and teaching assistantships.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

(Continued)

LIST OF FIGURES (CONTINUED)

LIST OF MAPS (IN POCKET)

LIST OF CROSS SECTIONS (IN POCKET)

LIST OF PLATES (IN POCKET)

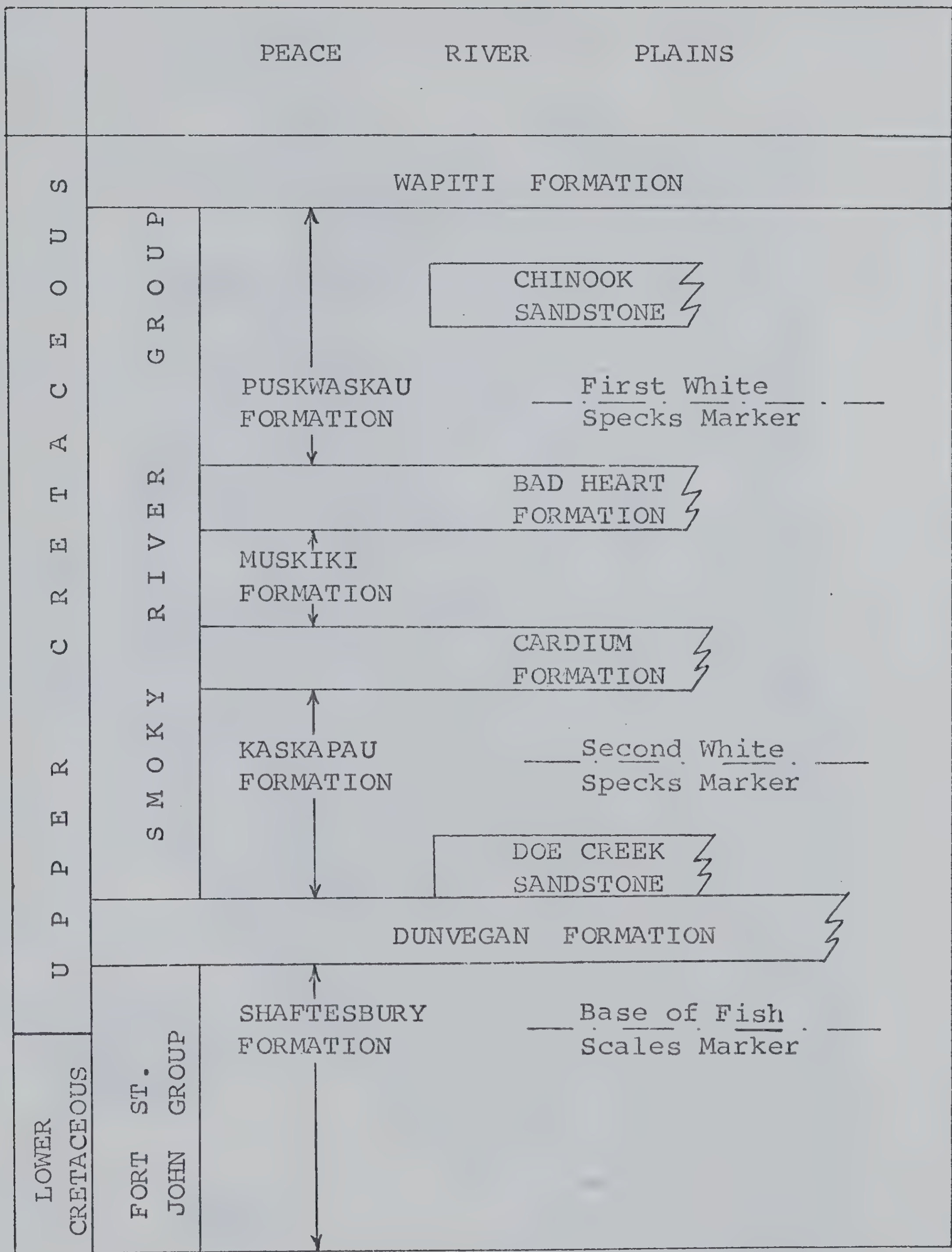
INTRODUCTION

PURPOSE AND LOCATION

The purpose of the study was to map and interpret the stratigraphy and lithofacies variations during deposition of the Upper Cretaceous Smoky River Group in the Grande Prairie Region of Alberta. This required regional correlation and mapping of the sand-shale sequence of the Smoky River Group, which includes the Doe Creek and Cardium sands of the Kaskapau Formation, and the Bad Heart and Chinook sands of the Muskiki and Puskwaskau Formations (Table 1). The map area runs from 54°00' N to 56°00' N and 118°00'W to 120°00' W, or, approximately townships 60 to 80 west of the sixth meridian in Alberta, about 9,800 square miles (Figure 1).

PREVIOUS WORK

Previous published work on the Upper Cretaceous marine section in the subsurface in the Grande Prairie Region is included in a paper by Burk (1963). Burk gives preliminary results of a regional subsurface stratigraphic analysis of the Upper Cretaceous in west-central Alberta and adjacent British Columbia. Additional litera-



(MODIFIED FROM STOTT, 1961)

Table 1. Stratigraphic section illustrating the Upper Cretaceous Smoky River Group sediments.

AREA

OF

STUDY

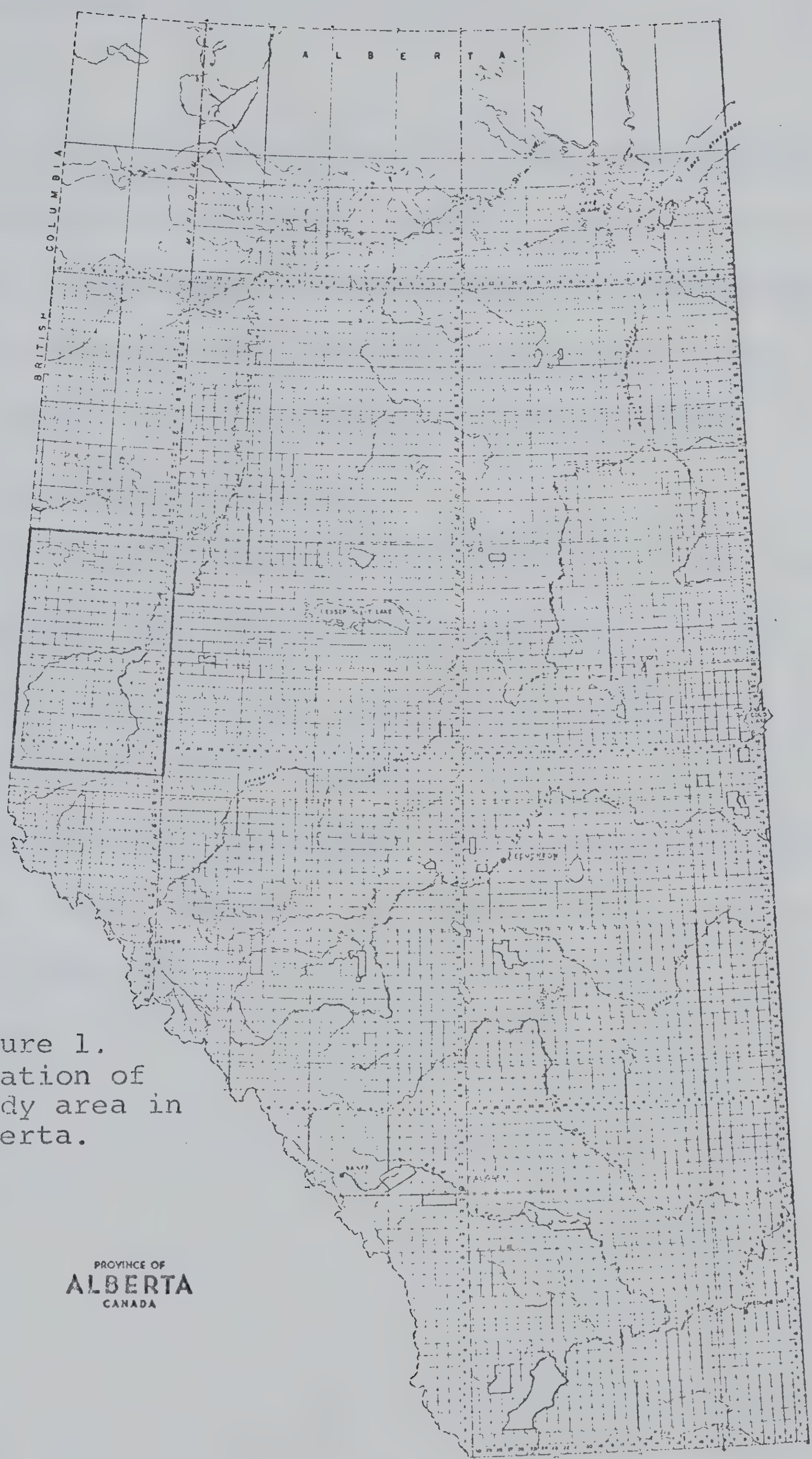


Figure 1.
Location of
study area in
Alberta.

ture is reviewed in the introduction of the report by Burk (1963).

Recently, most of the work in the subsurface has concentrated on the Cardium Formation, with the trend being to interpret processes and environments of deposition. Papers by Berven (1966), Crossfield-Garrington Area; Sinha (1970), Edson Area; and Michaelis and Dixon (1969) provide examples of this.

Three vertical successions interpreted using sedimentary structures and textures for recognition of depositional environments are discussed in a paper by Davies, Ethridge, and Berg (1970). Further examples are given in "The environmental characteristics of Upper Cretaceous units in the area of Helper, Utah" (Howard, 1971, unpublished literature of Union Oil Company).

METHOD OF STUDY

A total of 244 wells were selected for study, giving an average density of about one control well per township. In fact, every available well was used except in the far west between townships 77 and 80 W6M, where there are many wells (Pouce Coupe and S. Pouce Coupe gas fields). Here, an average of one well per township was selected in order to maintain uniform well density control.

The study began with detailed examination and logging of core. More than 1000 feet of core in 9 wells was logged. Each well contained Cardium core, three included Bad Heart, and one cut Chinook core. Only core in the southern half of the map area was examined, because this was slabbed (for the most part) and because the Cardium sandstone appeared to be best developed in this area.

Most of the logged core was photographed, 15 feet at a time, (the negatives were printed backwards so that the resulting photographs could be placed side by side and read continuously from top to bottom by scanning them from left to right) and an interpretation of environmental lithofacies was made of the Cardium photographs.

Generalized lithofacies were then interpreted from electric logs to extend the distribution of the Cardium and other Smoky River Group sands regionally over the entire area. Core examination of every well in the map area would have been too expensive and time consuming (58

wells cut core in the Upper Cretaceous Smoky River Group in the area of study).

The distribution of the lithofacies was mapped in both space and time using a somewhat experimental approach. Theoretical time lines were inserted between known time markers by simply subdividing the thickness using constant ratios. Thence it was possible to obtain a sufficient interplay of time lines with a rock unit (formation) in order to map its distribution time-wise. In the subsurface of the Grande Prairie region, the known time markers are the First and Second White Speckled shales. As earlier work has shown the First White Specks to be only slightly diachronous across a large region of Western Canada (Park, 1965), both these markers were assumed to be essentially isochronous within the limits of the map area.

Five theoretical time lines, calculated for the interval between the First and Second White Specks markers, were plotted on each well. The Cardium and Bad Heart Formations, time-transgressive rock units deposited within the interval between the First and Second White Specks, were mapped using this approach. The same technique, adapted for the purpose of mapping lithofacies in the Doe Creek Member, produced results considered to be acceptable within the limits of the inferences and assumptions inherent in the method.

It is emphasized that the method used in this study to map the lithofacies of the Smoky River Group sands is

an experimental approach. As a preliminary study initiated in an area having relatively sparse well control, it is probably safe to say that the method gives reasonable results to a first approximation.

In several wells, repeated sections (arising from thrust faulting in the adjacent disturbed Foothills belt), which were recognized had to be eliminated. The repeated sections were cut from the logs before the addition of the time lines. Recognition of repeated sections and their subsequent removal is an important procedure in the method. If omitted, anomalous lithofacies will be found because of the increased thickness of particular sections.

Another problem arises of course if there are unconformities present. An erosional hiatus gives rise to the absence of a variable thickness of rock, and the assumptions inherent in the uniform division of a section by theoretical time lines based upon known marker horizons become invalid. New time planes can be approximated above the hiatus, but must be problematical below unless it is possible to determine how much of the section has been removed.

STRATIGRAPHY AND GENERAL DEPOSITIONAL HISTORY OF THE UPPER CRETACEOUS IN THE GRANDE PRAIRIE REGION

This outline is intended to introduce the reader to the Upper Cretaceous stratigraphy in the subsurface of the Grande Prairie region. In addition, it gives an account of the general depositional conditions, based on the interpretations of previous authors. The distribution of the lithofacies of the Smoky River Group in the Grande Prairie region was mapped regionally in this study. The maps, interpretations, and conclusions of this study will be discussed later.

At the beginning of Late Cretaceous time, the interior of Western Canada was occupied by a broad, epeiric sea, extending in width from the present Rocky Mountains to east of the Manitoba escarpment, connected with the Arctic Ocean to the North and with the Gulf of Mexico to the South (Williams and Burk, 1964; Berven, 1966). Sediments deposited therein probably were derived from a rising borderland to the west (Berven, 1966; p. 210).

During this time, thick, dark grey, marine shales of the Shaftesbury Formation were deposited. A sandy zone containing fish remains, associated with the ammonite genus *Neogastroplites*, marking the Lower-Upper Cretaceous boundary,

occurs near the middle of the formation (Williams and Burk, 1964). It is called the Fish Scales zone and has been widely used as a subsurface datum in Alberta. The electric-log marker related to this zone and correlated in this paper (Cross sections 1 and 2) is a little lower than that used by Burk (1963). The concentration of fish remains could indicate volcanism which poisoned the sea, killing off the fish; or it may be a lag deposit representing a period of slow deposition (Williams and Burk, 1964).

During the Cenomanian Age, uplift and intrusion began to occur in north-central British Columbia. Coarse clastics, carried by easterly flowing streams, were deposited in northern Alberta (including the Grande Prairie region), and adjacent British Columbia as the Dunvegan delta complex (Burk, 1963; Fig. 10). Following the main episode of building the Dunvegan delta complex, the sea transgressed across these deposits.

Predominantly shaly beds of the Kaskapau Formation (the lowermost formation of the Smoky River Group) conformably overlie the Dunvegan. Although the source area was relatively stable at this time, periodic uplifts occurred and were recorded by influxes of coarser clastics

forming thin sandstone tongues. In the Grande Prairie region, the lower Kaskapau Formation contains one such sand, named the Doe Creek by Warren and Stelck, (1940).

Early in the Turonian, conditions of maximum transgression of the sea favoured deposition of calcium carbonate. In Western Canada (including the Grande Prairie region), calcareous white-speckled shales, known as the Second White Specks zone, were formed (Williams and Burk, 1964). The stratigraphic electric-log marker for this zone is chosen near the top of a shale of relatively high electrical resistance and corresponds to that used by Burk (1963).

Later, during mid-Turonian time, shallowing of the sea produced dark, non-calcareous shales. Shallowing continued during the late Turonian, as terrigenous clastics of the Cardium Formation caused the western shoreline to migrate seaward. The Cardium grades upward from the underlying Kaskapau shale into basal marine sandstone followed by non-marine sandstone, averaging sixty feet thick in the Grande Prairie region. The sandstone is overlain by non-marine shale, siltstone, and coal. Beach, barrier island, lagoon and tidal swamp deposits characterize much of the Cardium in the Grande Prairie region (Williams and Burk, 1964).

Renewed subsidence during Coniacian time shifted the shoreline generally westward across the map area, and the Cardium was overlain by the dark grey, marine shale named the Muskiki Formation by Stott (1961). These beds lie with slight disconformity on the Cardium in the Grande Prairie region. This disconformity, recognized in the subsurface, will be discussed in detail later.

Following deposition of the shales of the Muskiki Formation, the sea began to shallow once more with the onset of deposition of the Bad Heart sandstone.

> "The almost exclusively arenaceous assemblages of Foraminifera in the upper (Kaskapau) Muskiki shale indicate a quite shallow, probably cool water environment. Further shallowing of the sea just prior to deposition of the Bad Heart sandstone is suggested by the presence, for a short interval below the sand, of coarse-grained representatives of *Involutina*, *Haplophramoides*, and *Reophax*." (Wall, 1960; p. 13).

In the subsurface, the Bad Heart zone, from 40 to over 100 feet thick, is recognized from the resistivity logs; however, the spontaneous potential curves rarely indicate sandstones more than 80 feet thick. The Bad Heart probably grades from marine at the base to non-marine towards the top, as described by McLearn (1919). However, in the few cores examined from the Grande Prairie region, the formation appears to not have developed the various easily recognized lithofacies seen in the Cardium.

> "After the deposition of the Bad Heart, the water probably deepened somewhat, although remaining relatively shallow, as revealed by the assemblages of finely arenaceous species in the lower part of the Puskwaskau shale." (Wall, 1960; p. 13).

Several hundred feet of shale were deposited over the Bad Heart Formation in the map area during late Coniacian and early Santonian time.

> "The occurrence of the pelagic microfauna of Gumbelina and Globigerina to the virtual exclusion of arenaceous Foraminifera in the 'white-speckled shale zone' is indicative of further deepening and of a connection with a vast interior seaway to the south and east." (Wall, 1960; p. 13).

The "white-speckled shale zone" mentioned above is referred to as the First White Specks zone. The electric-log marker for this horizon used in this study again corresponds to that used by Burk (1963); chosen near the top of a shale of relatively high electrical resistance.

With the onset of tectonism in the Cordillera in the late Santonian, interbedded sand and mud were deposited as shoreline conditions oscillated across the present foothills position. In outcrop, west of the Grande Prairie region, five sand members (namely: Dowling, Thistle, Hanson, Chungo, and Nomad) in the Puskwaskau Formation have been recognized (Stott, 1961). The Chungo member is the most prominent, and occurs throughout the foothills. The equivalent sandstone occurs in the subsurface in the western part of the

Grande Prairie region, where it is named the Chinook sandstone (Stott, personal communication). Chinook sandstone core was examined in only one well (Bailey Selburn-Regent-C. F. P. Trail 15-30-64-9 W6M). Here the Chinook is about 50 feet thick and lithologically differs from the Cardium and Bad Heart sandstones in that it has much more glauconite and contains thin beds of conglomerate.

With further tectonism, the rate of sediment supply increased, and shifted the shoreline to the east (eventually as far as Saskatchewan). The Grande Prairie region during Campanian time underwent a major phase of continental deposition, beginning with the basal Wapiti sandstones.

CARDIUM LITHOFACIES

Cardium core was examined in detail in 9 wells over the southern part of the map area. The particular wells were selected because they contained the greatest amount of slabbed core, and because the corresponding electrical log characteristics were well developed. The purpose of the core study was to interpret the Cardium lithofacies and to relate them, if possible, to electrical log features.

Cardium lithology and sedimentary structures in the Grande Prairie area have much in common with the selected Cardium cores described by Michaelis and Dixon (1969). Interpretations of associated sedimentary environments in both Recent and ancient sandstones have been made, notably by Davies, Ethridge and Berg (1971), Pettijohn, Potter, and Siever (1965), and Howard (1971).

Following is a description of the most commonly observed features of the Cardium Formation in the Grande Prairie region. This may serve as a guideline for recognition of the Cardium lithofacies from core. The interpretations are based on similar features described by other authors.

CARDIUM LITHOFACIES

FACIES NAME

This study (1)*	Michaelis and Dixon (1969) (2): Selected Cardium cores, Alberta.	Davies, Ethridge, and Berg (1971) (3): Galveston/ Bell Creek/England.	Howard (1971) (4): Helper Area, Utah.
Facies "D" or Channel Facies.	Facies "D", sandstones with crossbedded fining-up units.	No equivalent facies is discussed except for the closely related deposits of a tidal channel interpreted from the Lower Jurassic strata of a thick barrier complex in southern England. Tidal channels present a vertical succession of structures and textures akin to fluvial channels (p. 563).	Channel-Fill deposits.

LITHOLOGY

(1) Sandstone: coarse, poorly sorted basal deposits, fining upwards to very fine to medium-grained crossbedded sandstone.

(2) Coarse, poorly sorted graded sandstone beds fining upwards and overlain by crossbedded very fine to medium-grained sandstones.

(3) Coarse, fragmental biosparites, upward vertical decrease in grain size.

*(NOTE: Number in parenthesis identifies the paper).

(4) Composed of sand very similar to that of the upper shoreface, with thinly bedded siltstones and shales, and stringers and lenses of carbonaceous material.

SEDIMENTARY STRUCTURES

(1) The sandstone is characterized by high angle cross-lamination of fairly large scale.

(2) Sandstone crossbedded on a large scale. At the tops of the crossbedded units there are usually intervals of finer argillaceous sandstone with climbing ripple lamination.

(3) These rocks are characterized by a vertical decrease in sedimentary structures from large scale festoon crossbedding near the base to microtrough cross-lamination toward the top of the channel sequence (p. 559).

(4) Most abundant physical structures are trough cross-laminae.

CONTACTS WITH ADJACENT FACIES

(1) Channel sandstones frequently interrupt intervals of lagoonal sediments (Photos 3 and 4- 41.5' to 47.5': Triad-Pan Am Haglund 6-25-66-13 W6M - 4145'-53'), or may be found resting on the beveled surface of Facies A sandstones (Bailey Selburn-Regent- C. F. P. Trail 15-30-64-9 W6M - 6473' - no photo). Younger channel deposits may be found beveled across and overlying older channel sequences (Triad-Pan Am Hazelmere 6-16-69-13 W6M - 3068'-76' - no photo). This sequence was probably formed by lateral migration of channels meandering in an alluvial floodplain.

(2) Facies D sandstones are found resting on the beveled surface of Facies A sandstones (p. 422). The sands were deposited from moderately strong, unidirectional currents. These either waned periodically or more probably migrated laterally... The sequence is typically developed in meandering channels (p. 420). Coarse graded beds occasionally found in the Cardium were probably deposited from high concentration suspensions in upper flow regime transport (p. 414).

(3) Channels may interrupt the typical vertical sequence of structures and textures, while lateral migration of channels may cause extensive areas of the barrier to be characterized by fluvial type sequence (p. 564).

(4) Commonly the underlying beach sequence is partly or completely removed by channel sandstones (p. 82).

BURROWING

(1) No Burrowing.

(4) Biogenic sedimentary structures nearly lacking.

FACIES NAME

(1) Restricted Bay or Lagoonal Facies.

(3) Lagoonal deposits.

(4) Lagoon - Swamp.

LITHOLOGY

(1) Mudstone: usually dark grey, may be light grey (Photo 1- 10' to 12': Bailey Selburn-Regent-C.F.P. Trail 15-30-64-9 W6M - 6420'-22'). Contains bituminous or coaly plant fragment remains and thin beds of coal (Photo 3- 30' to 42').

(3) Interbedded clay and silt with some fine-grained sand.

(4) Shaly material, thin sandstones and ripple-laminated siltstones rich in carbonaceous material, and coal.

OTHER DISTINGUISHING FEATURES AND INFERRED DEPOSITIONAL ENVIRONMENT

(1) Occasional interbedded very fine-grained sandstones are interpreted as washover sediments, deposited with abnormal increases in wave agitation during storms. The sandstones may also be interpreted as eolian deflation dune deposits (Triad-Pan Am Haglund 6-25-66-13 W6M - 4131'-34'; no photo).

The fine-grained sediment (mostly muds) with occasional well preserved fossils (Photo 3- 32.5': B.A. Musreau Lake 12-20-63-4 W6M - 5647'), and scattered plant fragments throughout suggests deposition in quiet water, typically found in the physically protected environment landward of a beach or barrier island.

The presence of plant remains and coal suggests possible proximity to a floodbasin, swamp, or marsh.

(3) An important constituent of the lagoons are "washover" sediments which consist of very fine-grained sands that are carried to the landward side of the barrier island by storm-driven water and wind and are deposited as coalescing fans that form a sand apron which extends into the finer-grained lagoonal sediments. Typically, the washover sands may be either structureless, due to burrowing or churning, or microcross-laminated, if deposited rapidly in shallow water. The structureless washover sands are difficult to distinguish from typical eolian sands of the barrier, but in general they contain more clay matrix indicating a low-energy environment of deposition (p. 553, 556).

(4) Sands interbedded with the silty shales are almost invariably ripple-laminated. Trace fossils that might serve to characterize the marsh or lagoon are not especially obvious, and some beds show a vague reworking of unknown origin (p. 82).

FACIES NAME

(1) Facies "A", Upper shoreface, or Beach/Barrier.

(2) Facies "A", tabular laminated sandstones: Facies A sandstones contain the record of constant oscillatory water motion characteristic of beaches or shoals (p. 415, 422).

(3) Beach-upper shoreface: These sediments probably originated on a beach or in adjacent shallow water (p. 554).

(4) Upper shoreface: An environment of significantly higher energy than those considered previously is indicated (p. 80).

LITHOLOGY

(1) Sandstone: fine to very fine-grained, medium to well sorted.

(2) Mainly very fine and fine-grained sandstone.

(3) Fine to very fine-grained sandstone.

(4) Clean, well sorted sands.

SEDIMENTARY STRUCTURES

(1) Characterized by low angle, tabular cross-lamination (Photos 4 to 9).

(2) Plane tabular bedded units separated by erosion surfaces beveled across underlying units at a low angle. This structure appears to have been formed by periodic planation during abnormal periods of high current activity, such as storms. The surface produced by this beveling then determined the attitude of the laminae during the next period of accretion. This process may occur on either beaches or shoals... (p. 415).

(3) Planar, low angle cross-lamination.

(4) Low angle, distinct lamination, truncated bedding planes. Truncation reflects the influence of storms, during which time the bottom was eroded to some depth then later rebuilt (p. 80).

RIPPLE STRUCTURES

(1) Occasional ripple and microcross-trough lamination.

(2) Ripple cross-lamination of lesser importance, symmetric, asymmetric and compound ripple lamination in some intervals (p. 419).

(3) Microcross lamination present sporadically: probably represents small asymmetric ripples developed under local conditions of reduced energy (p. 554).

(4) Ripple-laminae and trough cross-laminae are occasionally present.

GRAIN SIZE VARIATION

(1) Slight upward vertical increase in grain size: usually grades bottom to top from very fine sand to fine sand.

(2) Towards the base of the Facies A sandstone the grain size is finer.

(3) Upward increase in grain size.

SCOURS

(1) A few small scour and channel features (Photo 5- 67' and 69': Triad- Pan Am Grovedale 6-8-68-8 W6M - at 3748' and 3750' respectively).

(2) It is believed that scoured surfaces found in the Cardium were formed by stronger than normal currents, possibly related to storms (p. 416).

LAMINATIONS

(1) Laminations marked by colour banding from segregation of grains varying in size and composition on alternate laminae. The presence of mica accentuates this (Photo 8- 115'to 120': Triad-Pan Am Haglund 6-25-66-13 W6M - 4185'-90').

(2) It is believed that the plane lamination characteristics of many Cardium sand bodies is the product of oscillating currents produced by waves in shallow water (p. 415).

BURROWING

(1) Burrowing scarce.

(2) Bottom fauna could very well have existed but almost all trace has been obliterated due to constant fluid-sediment movement (p. 419).

(3) Burrowing scarce, shells may be locally abundant.

(4) Biogenic sedimentary structures are rare.

CONTACT WITH OVERLYING FACIES

(1) Upper few feet usually poorly laminated, possibly biogenically disturbed (by burrowing or plant rooting belonging to the overlying lagoonal facies). (Photos 4 and 5- 52' to 64': Triad-Pan Am Haglund 6-25-66-13 W6M - 4158'-70').

(3) True barrier sands will be flanked on their landward side by lagoonal sediments (p. 564).

(4) Beach cycle is overlain in most cases by sediments of the coal swamp or lagoon- consisting of shaly material containing lensing sand bodies and coal (p. 82).

CONTACT WITH UNDERLYING FACIES

(1) Grades downward into middle shoreface sands (Photo 9- 127.5' to 130': Triad-Pan Am Haglund 6-25-66-13 W6M - 4196.5'-99').

(2) Base of Facies A sandstone is gradational with the underlying Facies "B" section.

(3) The base of barrier sands is usually non-erosive. Beach-upper shoreface sediments gradationally succeed middle shoreface sediments.

FACIES NAME

(1) Middle shoreface facies (Photos 9 and 10).

(3) Middle shoreface

LITHOLOGY

(1) Sandstone: fine to very fine-grained, medium to well sorted. Characteristically massive, few sedimentary structures preserved.

(3) Consists of very fine-grained sand which is so extensively bioturbated that sedimentary structures are only rarely preserved. Therefore, middle shoreface sands are structureless and bioturbated (p. 552).

SEDIMENTARY STRUCTURES AND BURROWING

(1) Burrowing has completely homogenized the sediment, yet usually no evidence for intense burrowing activity can be found. In one well (Photo 9- 131' to 132.5': Triad-Pan Am Haglund 6-25-66-13 W6M - 4176'-77.5'), some of the trace fossils are preserved. At this particular location, perhaps the rate of sedimentation was greater, or the environment was not as suitable for as many organisms, so they have not completely obliterated their traces by homogenizing the sediment.

(3) The structureless nature of the sandstone is believed to reflect intense burrowing activity which has homogenized the sediment. This conclusion is supported by the presence of indistinct mottling and a few discontinuous or broken laminae. Distinct burrows are absent, probably because the sandstone is well sorted and lacks strong grain-size contrasts (p. 554).

CONTACTS WITH ADJACENT FACIES

(1) Grades upwards into upper shoreface sands; downwards into lower shoreface shaly sediments.

(3) The structureless very fine-grained sandstone originated in the middle shoreface zone of the barrier sequence, seaward of the beach but landward of the finer offshore siltstones (p. 554).

FACIES NAME

(1) Lower shoreface facies, or facies B_1 and C_1.

(2) Facies B_1, intermixed sandstone, siltstone and shale; and Facies C_1, shale with traces of siltstone.

(3) Lower shoreface.

(4) Lower shoreface, or simply, shoreface.

LITHOLOGY AND DISTINGUISHING FEATURES

(1) Intermixed sandstone, siltstone and shale; the sandstone and siltstone form distinct layers and lenses in the shale groundmass, with well defined burrows and trails (Photo 11- 155' to 165': Triad-Pan Am Haglund 6-25-66-13 W6M - 4241'-46'; and Bailey Selburn-Regent-C. F. P. Trail 15-30-64-9 W6M - 6540'-44'). There is another finer grained subfacies, consisting of shale with distinct laminae and lenses of siltstone with small burrows (Photo 12). These descriptions correspond closely to facies described by Michaelis and Dixon (1969). The lower shoreface rocks lack carbonaceous material thereby distinguishing them from the lagoonal facies. These shales are harder and more fissile than the mudstones of the lagoonal facies.

(2) Dominance of deposition from suspension is indicated by the fine grain size of both the B_1 and C_1 facies. The regular interbedding of silt and clay and the cross-lamination of the silt records fluid motion competent enough to maintain suspension and permit segregation of silt and clay. Sedimentation rates were fairly low, permitting segregation and traction of the silt (p. 420).

(3) The sediments:-- interbedded, burrowed, and churned (bioturbated), very fine-grained sand, silt, and silty clay (p. 552). Fine-grained rocks of this unit have at least 50 percent matrix and are interpreted as lower shoreface sediments deposited seaward of the barrier (p. 554).

(4) The lower shoreface is composed of fine to medium-grained dirty sand (this is coarser-grained than the corresponding lithofacies described by the other authors, nevertheless, most of the other features are similar). There are abundant, well-defined trace fossils, nearly every bed has been bioturbated, although there is always some remnant of primary lamination (p. 77).

FACIES NAME

(1) Offshore Facies, or Facies C_2.

(2) Facies C_2.

(4) Offshore Facies.

LITHOLOGY

(1) Shale: with indistinct mottles of silt, thorough bioturbation (Photo 13).

(2) Shale, with indistinct mottles of silt. Dominance of organic reworking is recorded in Facies C_2 (p. 420).

(4) Siltstone: essentially no physical sedimentary structures. The most obvious feature of this facies is that it has been completely reworked and churned by organisms (p. 74).

DEPOSITIONAL ENVIRONMENT

(1) Deposited in quieter, deeper water seaward of the lower shoreface sediments.

(4) It is believed that this was a relatively low energy environment with no significant effects of currents or waves (p. 75).

RELATING CARDIUM LITHOFACIES TO ELECTRICAL LOG CHARACTERISTICS

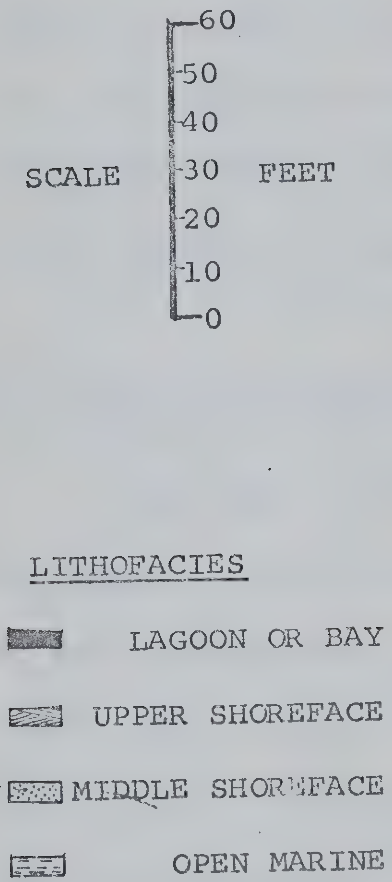
To map the distribution of the lithofacies of the Cardium Formation regionally, it was necessary to supplement core examination with the more widely available mechanical log data. The electrical logs, suitable for sand-shale sequences, were used because they were the most widely available.

The lithofacies defined from core examination of several wells were related to the recorded electrical log (particularly spontaneous potential) characteristics of these wells in the hope that the lithofacies could be interpreted from logs. Examples of the relationships follow. The lithofacies, interpreted from core, are schematically drawn on the electric logs.

<u>Well and Location</u>	<u>Cored Interval</u>
1. C. F. P. Cutbank East 16-4-64-6 W6M (Fig. 2).	5250'-5310'

This well has a simple sequence of facies which correlates with the electric-log characteristics. For example, the clean upper shoreface sands correspond to the S. P. log interval having greatest negative deflection.

(NOTE: In all diagrams involving logs, the left hand curve is Spontaneous Potential and the right hand curve is Resistivity).



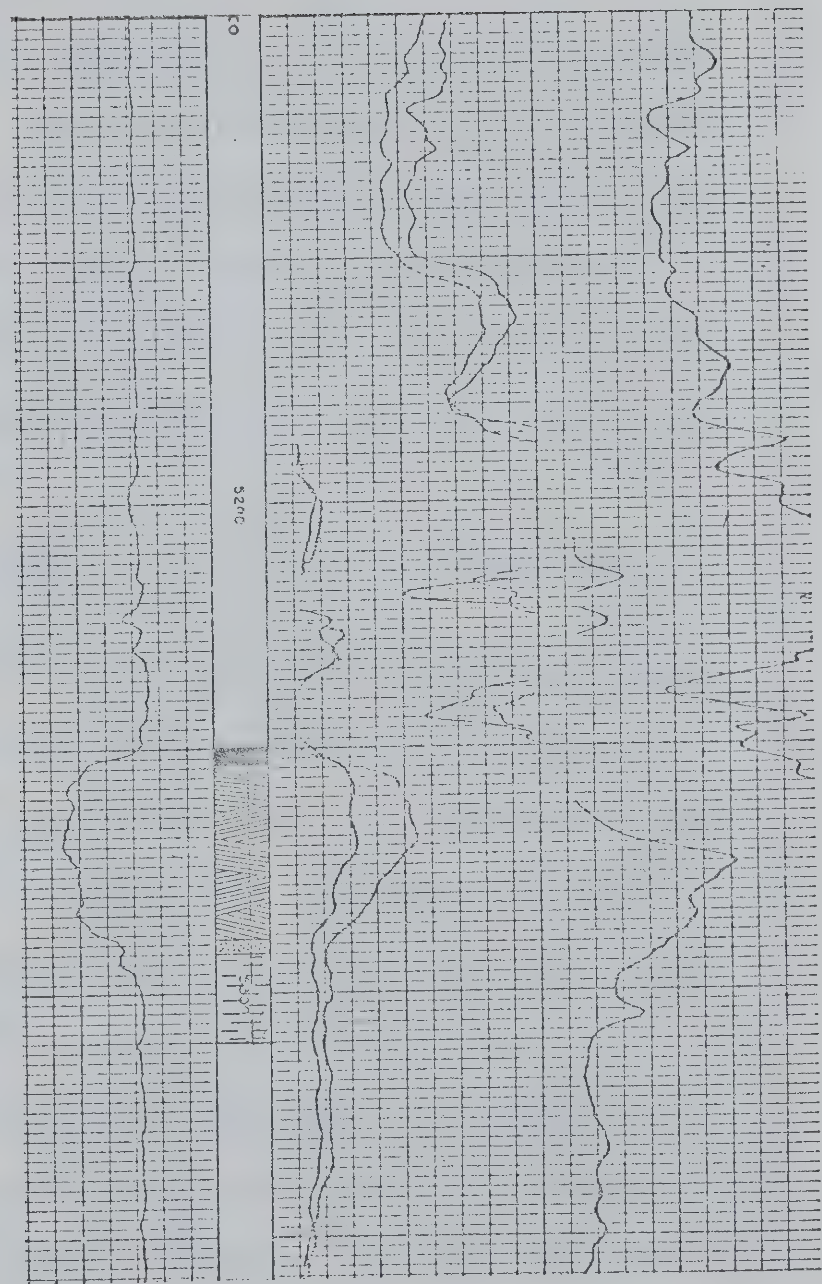


Figure 2. Cardium lithofacies from core related to electric-log character. C. F. P. Cutbank East # 16-4-64-6 W6M. Cored interval: 5250' - 5310'.

2. B. A. Musreau Lake 5585'-5739'
12-20-63-4 W6M (Fig. 3).

A straighforward sequence of facies correlates well with the electrical log characteristics. A channel sandstone interrupts the interval of lagoonal muds which overlie the beach/barrier sands. There is a corresponding S. P. deflection from the shale base-line on the left-hand side and a resistivity break on the right-hand side of the log.

3. Bailey Selburn-Regent- C. F. P. 6384'-6547'
Trail 15-30-64-9 W6M (Fig. 4).

Here the lithofacies do not consistently correspond to expected electric-log characteristics. For example, there is anomalously poor negative S. P. deflection in the lower portion of the beach/barrier sandstone, interval 6502'-6513', (explained later). Without core, this might have been interpreted as lower shoreface facies.

The interval with good negative S. P. deflection, 6453'-6502', would intuitively be expected to correspond to beach/barrier sandstone. However, from the core the upper 19 feet (6453'-6472') of this is interpreted as channel sandstone. The break in the resistivity curve is possibly the clue to this change.

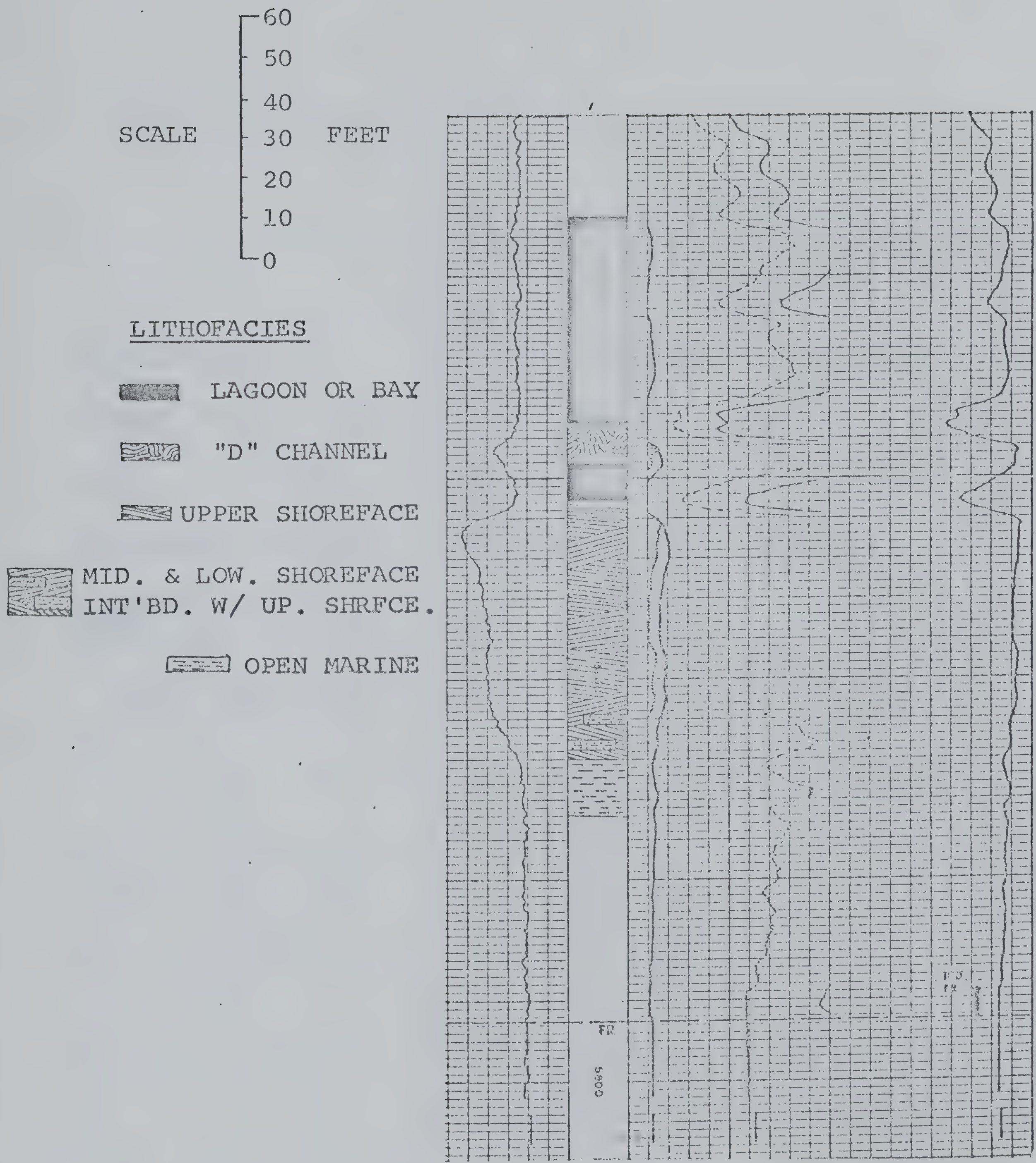


Figure 3. Cardium lithofacies from core related to electric-log character. B. A. Musreau Lake 12-20-63-4 W6M. Cored interval: 5585' - 5739'.

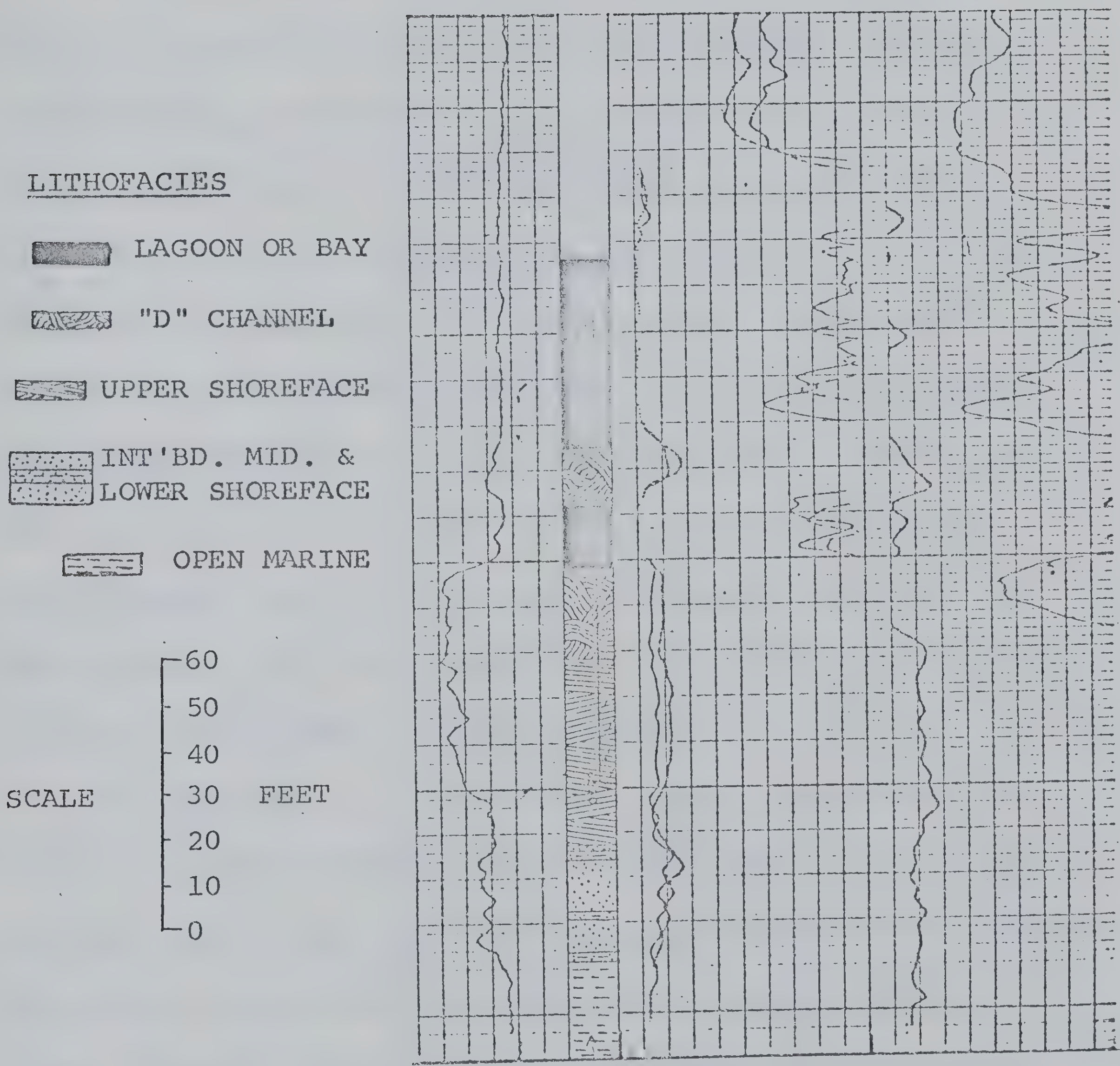


Figure 4. Cardium lithofacies from core related to electric-log character. Bailey Selburn-Regent-C. F. P. Trail 15-30-64-9 W6M. Cored interval: 6384' - 6547'.

4. Triad Oil Co. - Pan-American 3068'3154'
Hazelmere 6-16-69-13 W6M (Fig. 5).

Again, the lithofacies do not consistently correspond to expected electric-log characteristics. In the cored interval from 3068' to about 3118', the log has strong negative S. P. deflection. The expected corresponding lithofacies is beach/barrier sandstone. From core study, it is found that the upper portion, 3068'-3094', consists of well developed channel facies, which is also compatible with a strong resistivity deflection on the log. The remaining interval, 3094'-3118', should then be the beach/barrier facies. From core examination however, approximately the lower half (3106'-3118') of this interval is found to be middle shoreface facies.

To conclude, it appears that though one can use electrical log characteristics for a broad interpretation of Cardium lithofacies, the few examples examined in this study show that in detailed interpretations discrepancies may arise. Some are likely due to variations in porosity and permeability, as a result of differences in post-depositional diagenetic processes, such as cementation. Others may be caused by anomalous responses to spurious electrochemical factors related to the logging technique. Although inconsistencies arise in recognizing detailed lithofacies, it

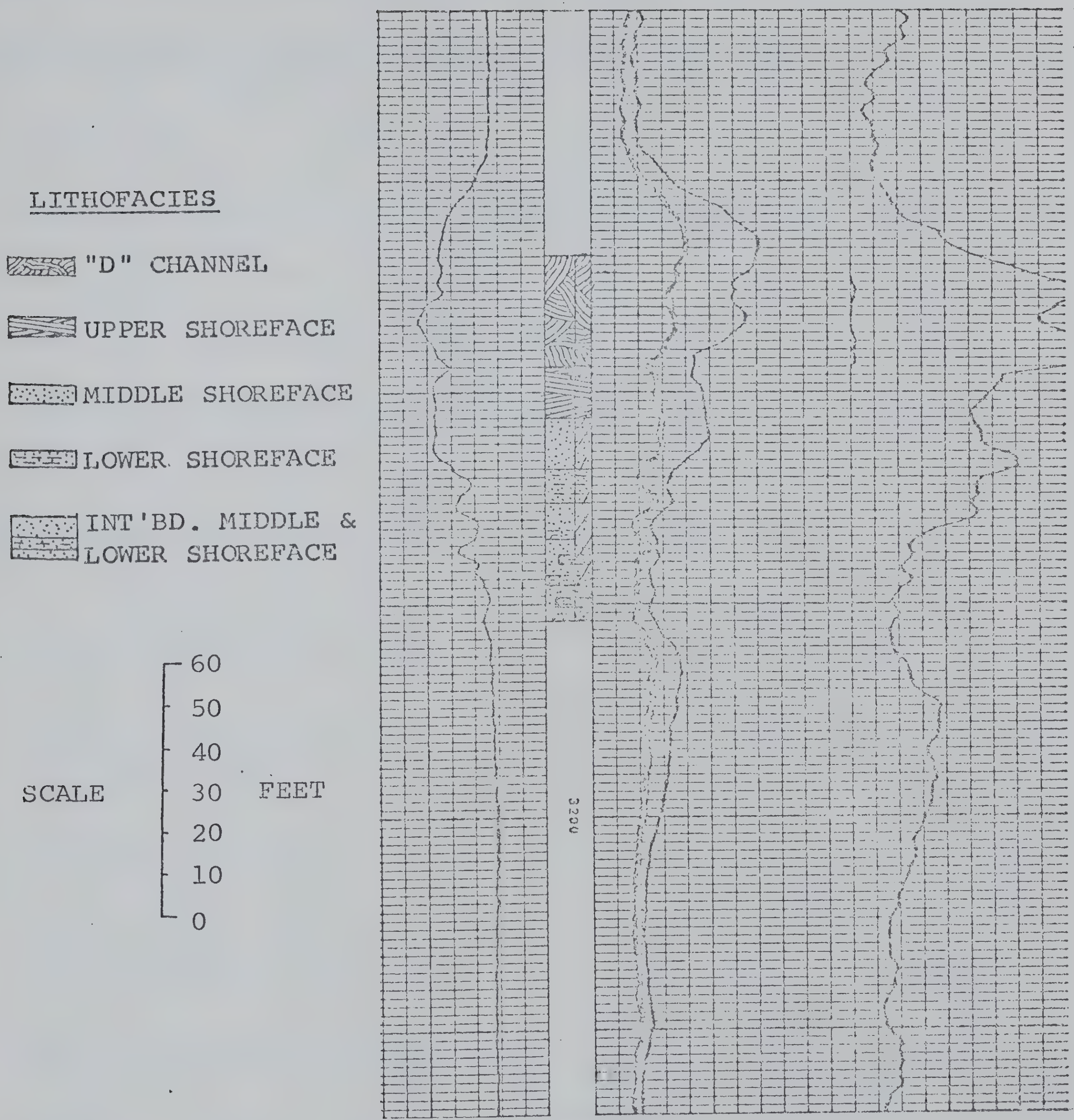


Figure 5. Cardium lithofacies from core related to electric-log character. Triad - Pan Am Hazelmere 6-16-69-13 W6M. Cored interval: 3068' - 3154'.

was felt that gross lithofacies correlations could be extrapolated by means of logs over the map area.

USING ELECTRICAL LOGS FOR REGIONAL MAPPING OF CARDIUM LITHOFACIES

Two methods were attempted; one quantitative, the second qualitative. The first method was abandoned (for reasons explained below), but it is outlined here because it could probably be applied in areas which have greater well and core control. The second, qualitative approach produced reasonable maps considering the relatively poor well and core control in the Grande Prairie region.

Method 1: Quantitative End - Member Mapping.

This is a statistical approach to mapping which has been described by Krumbein and Sloss (1963). The thicknesses of various lithofacies over given intervals in each well must be measured. For example, one interval could be defined to include everything between the Second White Specks and First White Specks markers. However this includes two sandstone formations, the Cardium and Bad Heart. It would probably be better to consider an interval which generally included only one sandstone formation; for instance it could be chosen to include everything between the Second White Specks and a point half-way between the First and Second White Specks markers. This interval, or slice, named slice No. 1, is shown in Figure 6.

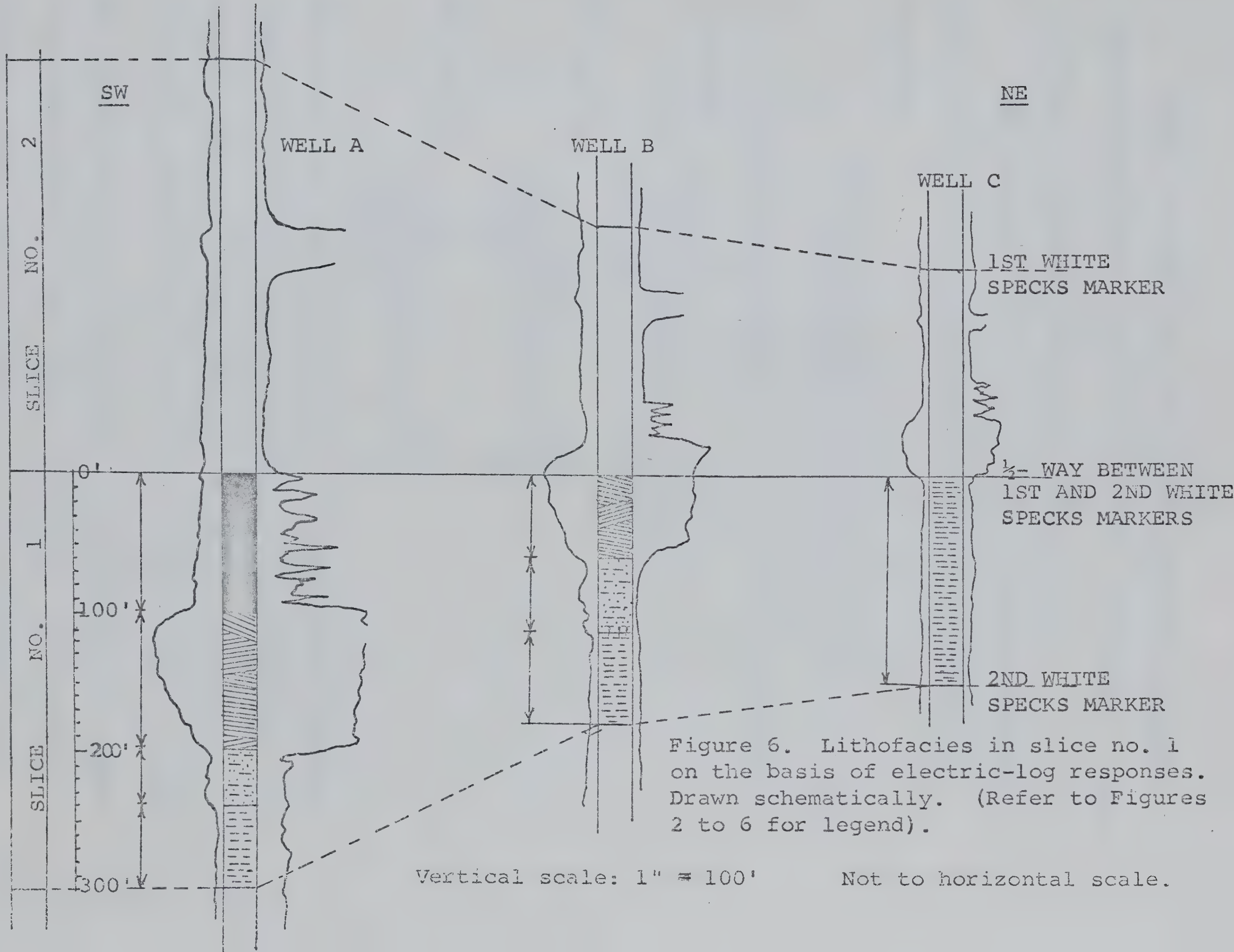


Figure 6. Lithofacies in slice no. 1 on the basis of electric-log responses. Drawn schematically. (Refer to Figures 2 to 6 for legend).

Vertical scale: 1" = 100'   Not to horizontal scale.

Using a triangle for three-pole end-member mapping, it would be necessary to group some of the lithofacies as shown in Figure 7 (Krumbein and Sloss, 1963; p. 458).

The measured thicknesses of the lithofacies in each well would then be converted into percentages using the formula:

$$\frac{\text{Measured Thickness of Each Lithofacies}}{\text{Total Thickness of Slice No. 1}} \times 100$$

The percentage distribution of the lithofacies in well A would be:

- open marine: 33 1/3%
- upper shoreface: 33 1/3%
- lagoon: 33 1/3%

In well B:

- open marine: 66%
- upper shoreface: 34%
- lagoon: 0%

In well C:

- open marine: 100%
- upper shoreface: 0%
- lagoon: 0%

Each well could then be plotted on the end-member triangle (Fig. 7). It would then be possible to superimpose an entropy function overlay onto the triangle. The entropy function applied to the 100-percent triangle gives a single set of contour lines that display the interrelations among three end members. This function expresses the degree of "mixing" of the rock components in a stratigraphic unit. The function is set up so that a section with equal parts

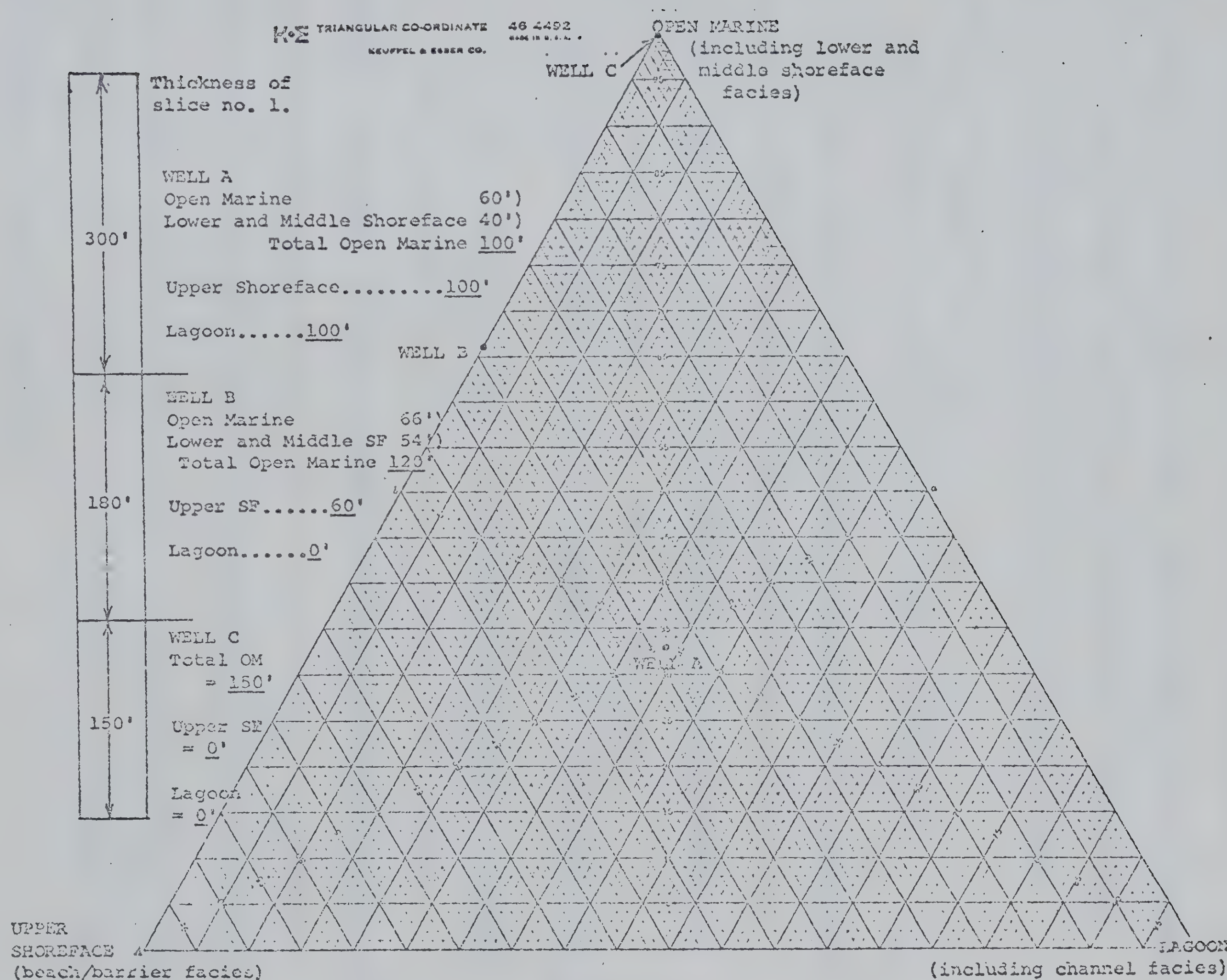


Figure 7. End-Member triangle.

of open marine, upper shoreface, and lagoonal lithofacies has an entropy value of 100, and as the proportion of one end member or another increases, the entropy value becomes smaller, approaching zero as the composition approaches that of a single end member (Krumbein and Sloss, 1963; p. 465, & Fig. 12-9).

The entropy figures could in turn be plotted on a map and then contoured. The map would show the total distribution of lithofacies deposited during the period of time given by slice No. 1. The procedure could be repeated to map the interval given by slice No. 2 (Fig. 6).

The quantitative method of mapping was not used because it would have required detailed interpretation and measurement of the lithofacies from logs. This is not always reliable, as shown in the previous discussion which related Cardium lithofacies seen in core to electrical log characteristics. The method would be even less reliable for slices which included the other sandstones of the Smoky River Group. Sufficient accurate data were not available to warrant the quantitative mapping approach.

Method 2: Qualitative Mapping Using Theoretical Time Lines.

To begin with, only the interval between the First

and Second White Specks markers was mapped. This includes the Cardium and Bad Heart sandstone, which were both studied in detail from cores. The Second White Specks marker has been shown to be a good time line (Park, 1965), and the First White Specks is assumed to be essentially isochronous across the map area, as explained in the method of study.

A true isochronous marker, or time line, records a given geological event or occurrence which took place approximately simultaneously over a wide area. The event is often recorded in the rock record by the widespread disappearance of a non-facies controlled fossil or group of fossils.

Where a formation climbs stratigraphically relative to a time line, it was probably deposited as a time transgressive or regressive unit, that is to say, it was not deposited everywhere at the same time. In cross section 1, the Cardium Formation climbs stratigraphically relative to the Second White Specks towards the SW. It appears therefore that the Formation is older the NE and younger to the SW. This interpretation is based on the supposition that all time lines above the Second White Specks are parallel to it (Fig. 8).

At least 400 feet of sediments are present between the

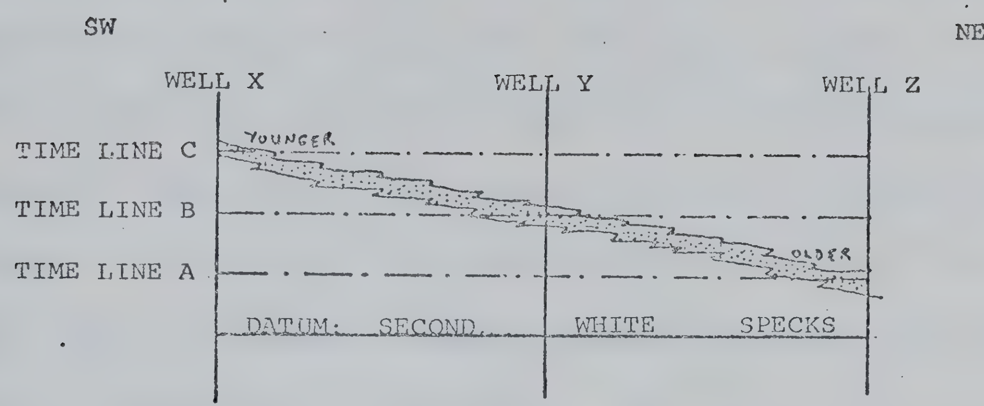


Figure 8. Theoretical time lines drawn parallel to the Second White Specks marker.

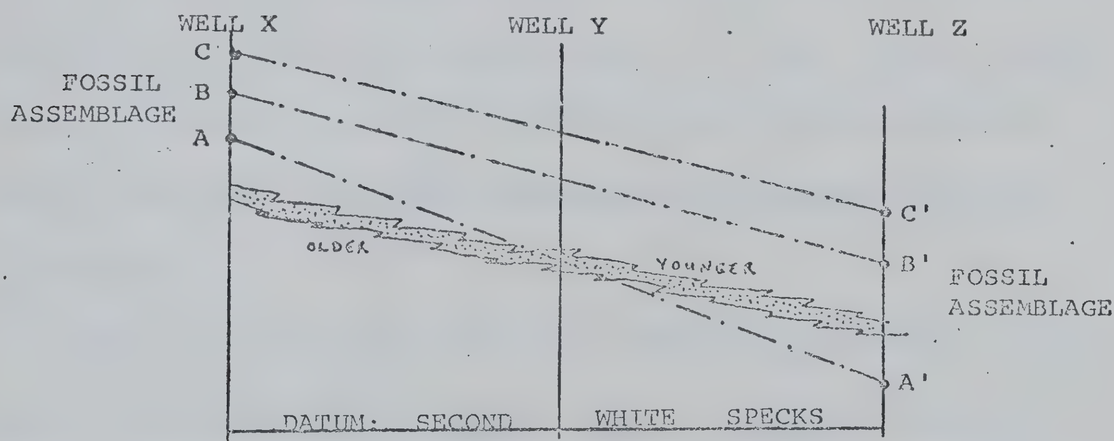


Figure 9. Time lines based on theoretical fossil assemblages.

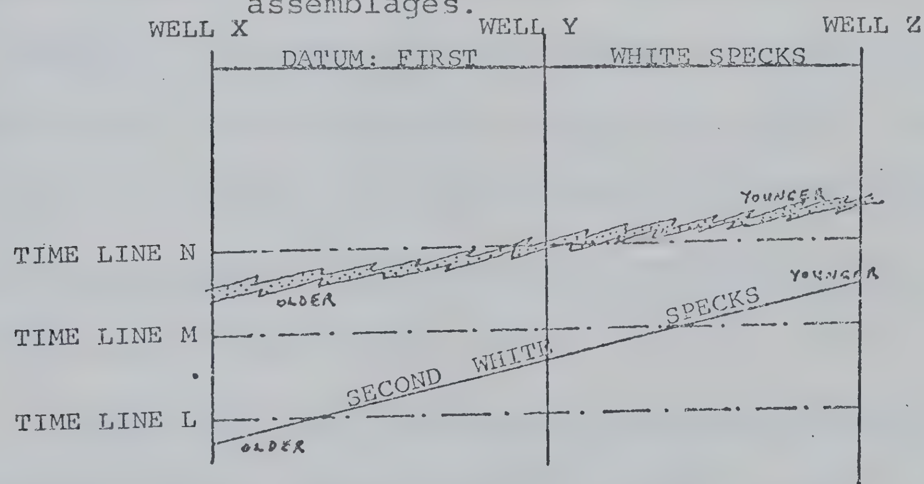


Figure 10. Theoretical time lines drawn parallel to the First White Specks marker.

Second White Specks marker and the Cardium sandstone. This interval thickens to more than 800 feet to the SW. It is conceivable that during the time these sediments were deposited, time planes were not parallel to the Second White Specks. For example, assume fossils A and A' are the same age, likewise B and B', and C and C', and they occur as shown schematically in Figure 9. With time lines, A-A', B-B', and C-C' the Cardium sandstone occurring SW of well Y is older than that found NE of well Y. This cross section shows that the climbing of the Cardium in the section is due strictly to a thicker section of preserved sediments to the SW.

Now consider using the First White Specks as a datum plane. The theoretical time lines L, M, and N (Fig. 10) drawn parallel to the First White Specks show how illogical it would be to assume all time planes to be parallel to this datum. The Cardium here would be older to the SW and younger to the NE, as would be the Second White Specks. This is incorrect because the Second White Specks is known to be nearly isochronous.

True time lines are probably subparallel to the First and Second White Specks markers, and may eventually be identified by detailed paleontological study.

In this study, five theoretical time lines designated by Roman numerals, were selected between the First and Second White Specks. The relative position of each one is explained in Figure 11. The time lines were plotted on every well. This method assumes that the rate of deposition (net result of rate of supply against rate of subsidence), varied uniformly across the map area, during the period of time bounded by the First and Second White Specks markers.

It is true that this assumption does not provide time lines which are completely accurate. However, this approximation of time line mapping was used because it was thought that it would produce meaningful lithofacies maps. Straighforward isopach mapping is useful for making initial interpretations, shown in a previous study, but tends to make the sandstones resemble blanket deposits since the time factor is not taken into account (Burk, 1963). With the fairly successful interpretation of lithofacies from core (especially in the Cardium), and recognition of the lithofacies as regressive deposits which moved across the map area, time line mapping is advantageous in showing their distribution at several different times. The theoretical time lines may eventually by proven to be cutting slightly

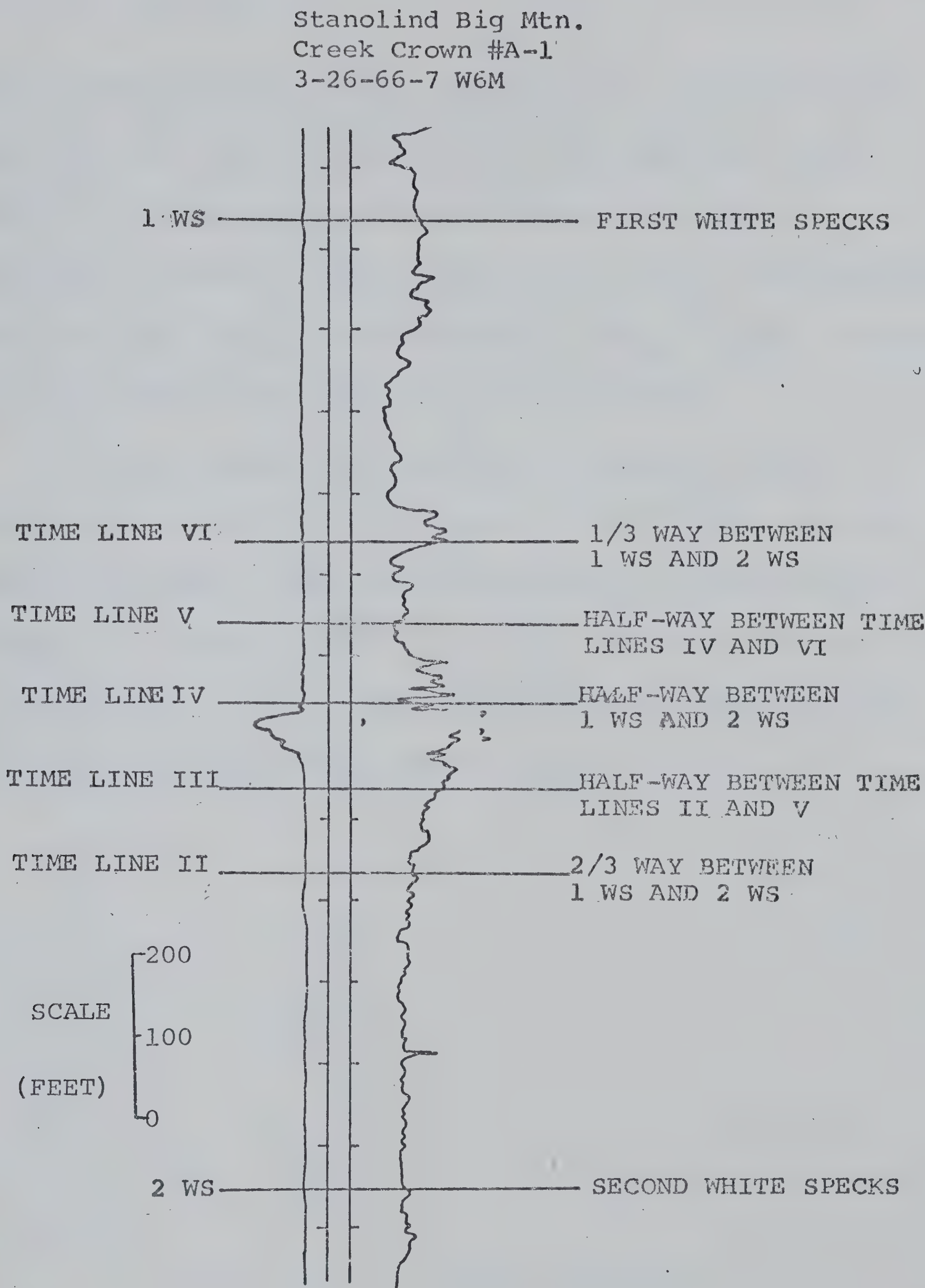


Figure 11. Five theoretical time lines selected between the First and Second White Specks markers.

up or down in time. If so, the points of intersection of the wells by time lines and thence the geographic positions of the boundaries between lithofacies would be affected. However, if the implications of the inaccuracies are realized, it is still possible to gain a useful picture, only the details of which may be in some doubt.

Before mapping the sandstones regionally, some generalizations of the lithofacies of the Cardium and Bad Heart were made. They are illustrated on a sample log in Figure 12, and described in Table 2. Each well was interpreted to be in one of these lithofacies at each position where a time line intersected the well.

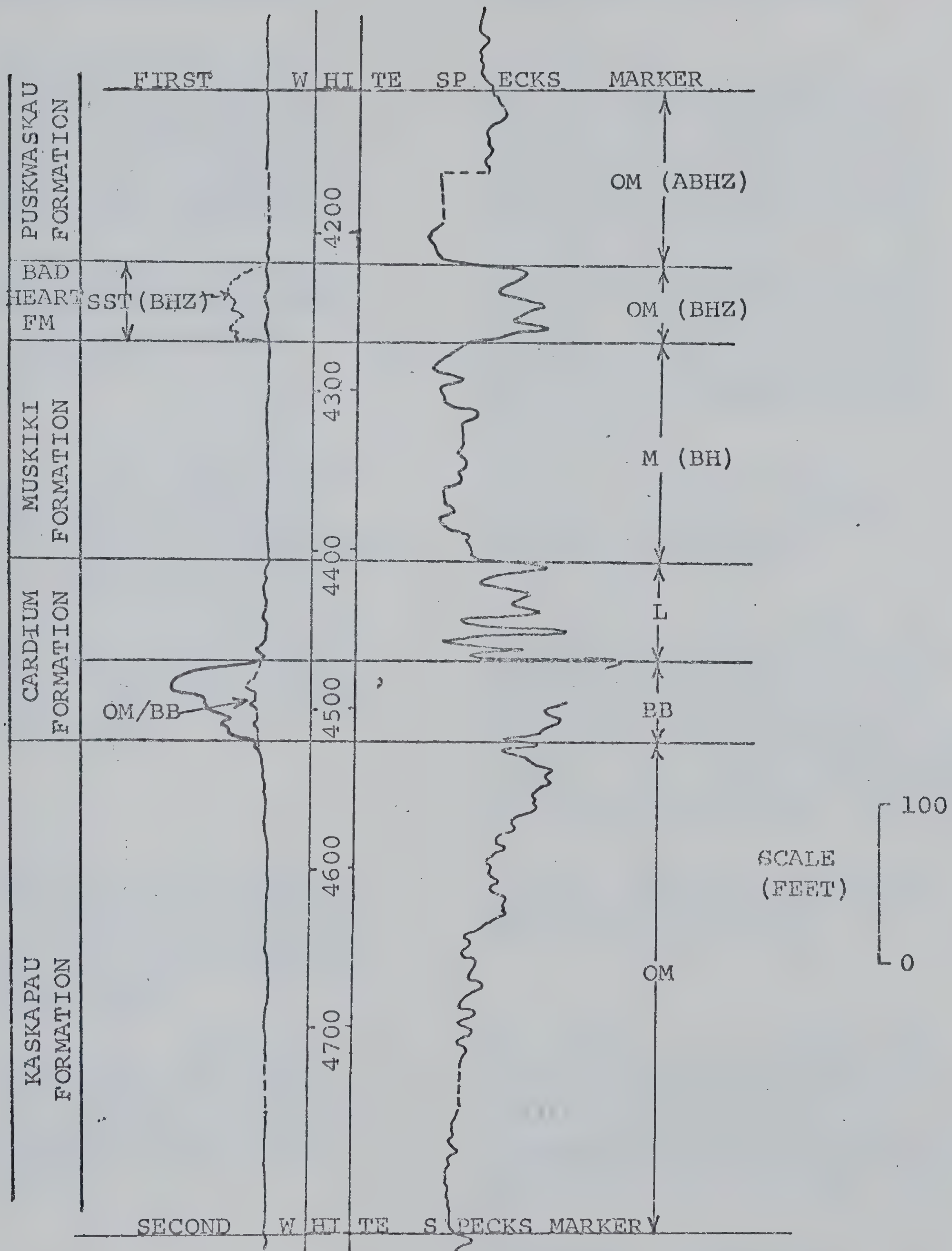


Figure 12. Generalized lithofacies related to the Cardium and Bad Heart between the First and Second White Specks markers. For explanation of symbols see Table 2.

LOG CHARACTERIZATION	LITHOFACIES DESIGNATION
Minimal S. P. and resistivity response between the Second White Specks and the base of the Cardium sandstone.	OM - Open marine facies (including lower shoreface and possibly some middle shoreface sediments) deposited prior to Cardium beach/barrier facies.
Strong S. P. and resistivity deflection associated with Cardium sandstone.	BB - Upper shoreface, beach/barrier island facies of the Cardium. It could include some middle shoreface sandstone below and some channel sandstone facies above.
Poor S. P. and rather poor resistivity deflection associated with the Cardium sandstone.	OM/BB - Poor development of a beach or barrier -example: Localized development of a small offshore bar.
Little S. P. deflection but strong resistivity kicks above the Cardium sandstone.	L - Lagoonal facies: the resistivity log usually has characteristic high deflection probably due to the associated carbonaceous matter in these mudstones. Some channel sandstones may be grouped in this interval.
Low S. P. and resistivity deflection above the Cardium zone and below the base of the Bad Heart zone.	M (BH) - the marine shales between the Cardium and the base of the Bad Heart zone.
Good S. P. and resistivity response associated with well developed Bad Heart sandstone.	SST (BHZ) - this interval defines the Bad Heart zone with significant development of sandstone giving noticeable S. P. deflection from the shale baseline.

(Continued...next page)

Table 2. Log characteristics upon which the choice of lithofacies is based, between the First and Second White Specks markers.

LOG CHARACTERIZATION	LITHOFACIES DESIGNATION
Poor S. P. response but usually rather good resistivity response defining the Bad Heart zone.	OM (BHZ) - This interval defines the Bad Heart zone with no significant development of sandstone: corresponding low deflection from the shale base-line.
Poor S. P. and resistivity response associated with deposits overlying the Bad Heart zone.	OM (ABHZ) - Open marine shales deposited above the Bad Heart zone.

Table 2 (Continued). Log characteristics upon which the choice of lithofacies is based, between the First and Second White Specks markers.

MAPPING THE DOE CREEK SANDSTONE

The Doe Creek is the oldest sandstone member of the Smoky River Group. Its distribution was mapped in relation to a point in time given by theoretical time line I (Map 1). Time line I is defined by the formula:

$$\left(\text{Second White Specks Marker (depth)} + \text{Base of Fish Scales Marker (depth)}\right) \times \frac{2}{5} = \text{Time}$$

Originally, it was intended that the half-way point between the Base of Fish Scales and Second White Specks markers define time 1. However, this line intersected too many wells too far below the Doe Creek.

Beginning in the northern part of the map area, time line I consistently intersects the wells much below the Doe Creek (i.e. in the Dunvegan). Moving slightly southward, time line I intersects the wells progressively nearer and nearer to the Doe Creek. Centre of gravity mapping was used to show this progression. Procedure: (refer to Fig. 13)... The distance (X) from the Doe Creek zone pick to the centre of Doe Creek sandstone development and the total distance (Y) between the Doe Creek zone pick and time line I were recorded.

The ratio, X/Y x 100, gives the relative centre of

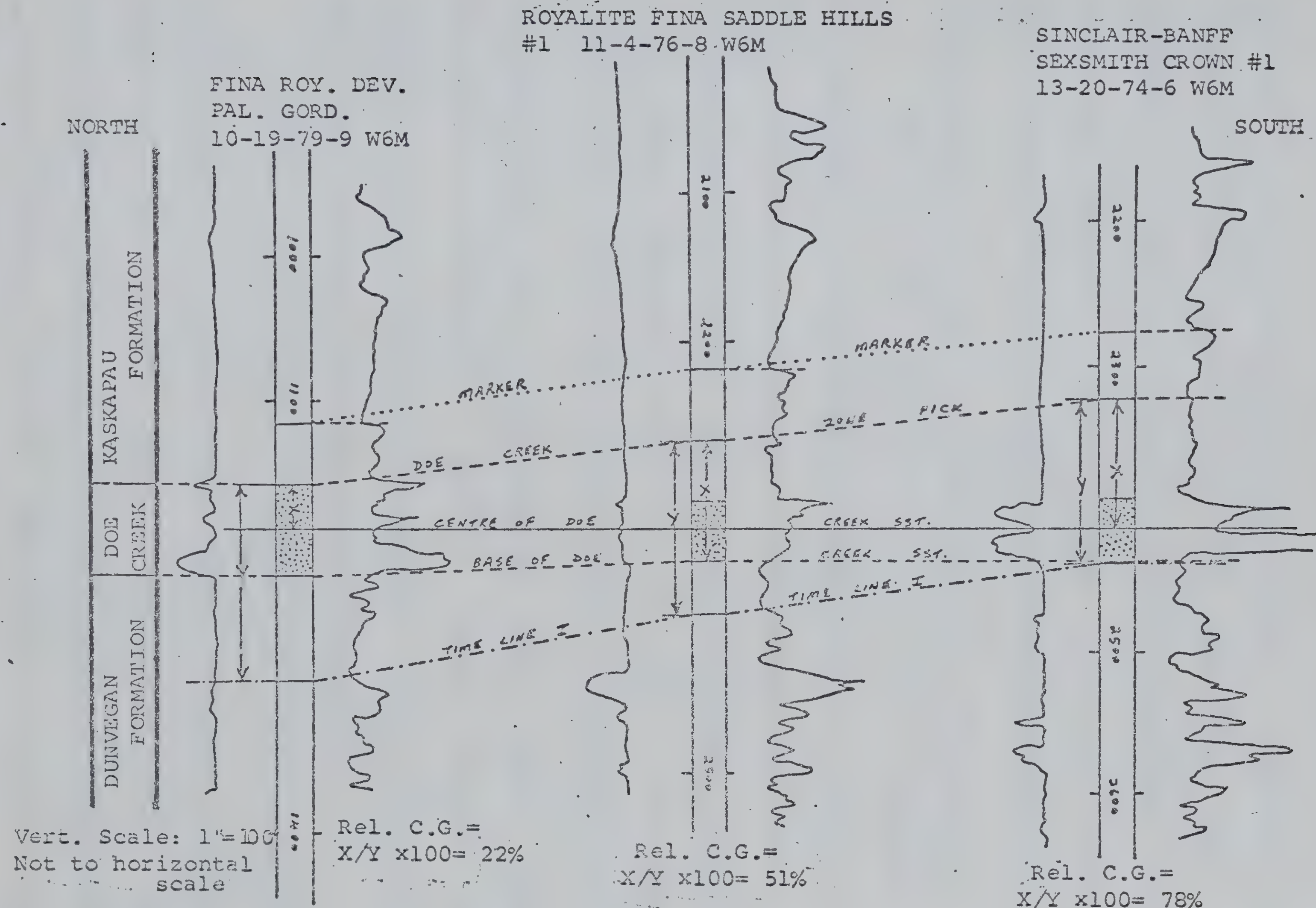
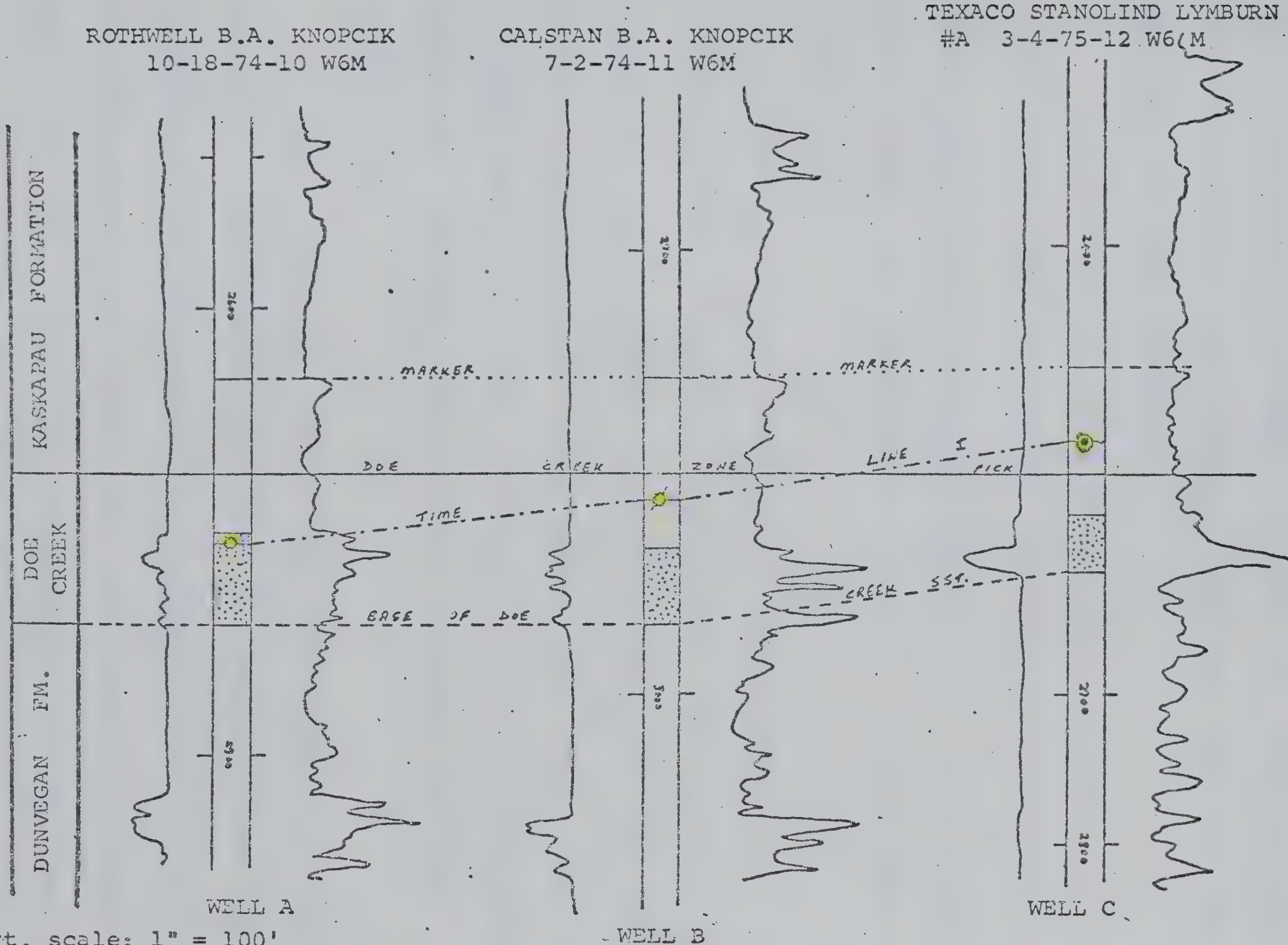


Figure 13. Method of mapping lithofacies related to the Doe Creek in wells where time line I intersected below the Doe Creek.

gravity (%), (Krumbein and Sloss, 1963; p. 479). The smaller the value of the relative centre of gravity, the longer Doe Creek deposition was from occurring. The greater the value, the nearer Doe Creek deposition was to occurring relative to time I. These values were calculated for every well in which time line I intersects the well below the base of any Doe Creek sandstone development.

If time line I intersects in Doe Creek sandstone, a yellow dot is assigned to the well (Fig. 14 - well A). If it intersects above sandstone development but below the Doe Creek zone pick, then a yellow dot with a black slash is the designation (Fig. 14 - well B). If it intersects the well at a point above both the Doe Creek sandstone and the zone pick, then a two-colour dot (green centre, yellow outside) is used (Fig 14 - well C). Green indicates that open marine deposition was occurring at time I, while yellow means that sandstone was deposited previously.

Several other facies, designated by other colours, appear on Map 1. To the north, where time line I intersects many wells below the Doe Creek, another two-colour dot is used; yellow in the centre and blue outside. The blue designates that Dunvegan sediments were being deposited at time I, but that Doe Creek sands (yellow) were to be deposited in



Vert. scale: 1" = 100'
Not to horizontal scale.

Figure 14. Method of choosing Doe Creek lithofacies when time line I intersected in the Doe Creek, and just above the Doe Creek.

the near future (Fig. 15-a). The relative centre of gravity percentage accompanying each dot gives an approximate evaluation of how long away the Doe Creek sand deposition was from happening.

In a few wells in the northern part of the map area, a solid blue dot was plotted. This represents facies in which Dunvegan deposition was occurring at time I, but where no Doe Creek sandstone was to form in the future (Fig. 15-b).

Finally, two more facies were plotted on Map 1. The solid purple dot is used for wells where time line I intersects just below the Doe Creek zone pick, but where no sandstone was developed (Fig. 15-c). The solid green dot is used where time line I intersects above the Doe Creek zone pick, but where there was no sandstone developed (Fig. 15-d).

Map I shows the distribution of the Doe Creek lithofacies at approximately one point in geologic time, given by theoretical time line I. It suggests that a NW - SE trending zone of Doe Creek sands was being deposited at this time. The sands were ultimately distributed over much of the map area. To attempt to show this, two-colour dots were used. In addition, an isopach map of the Doe Creek

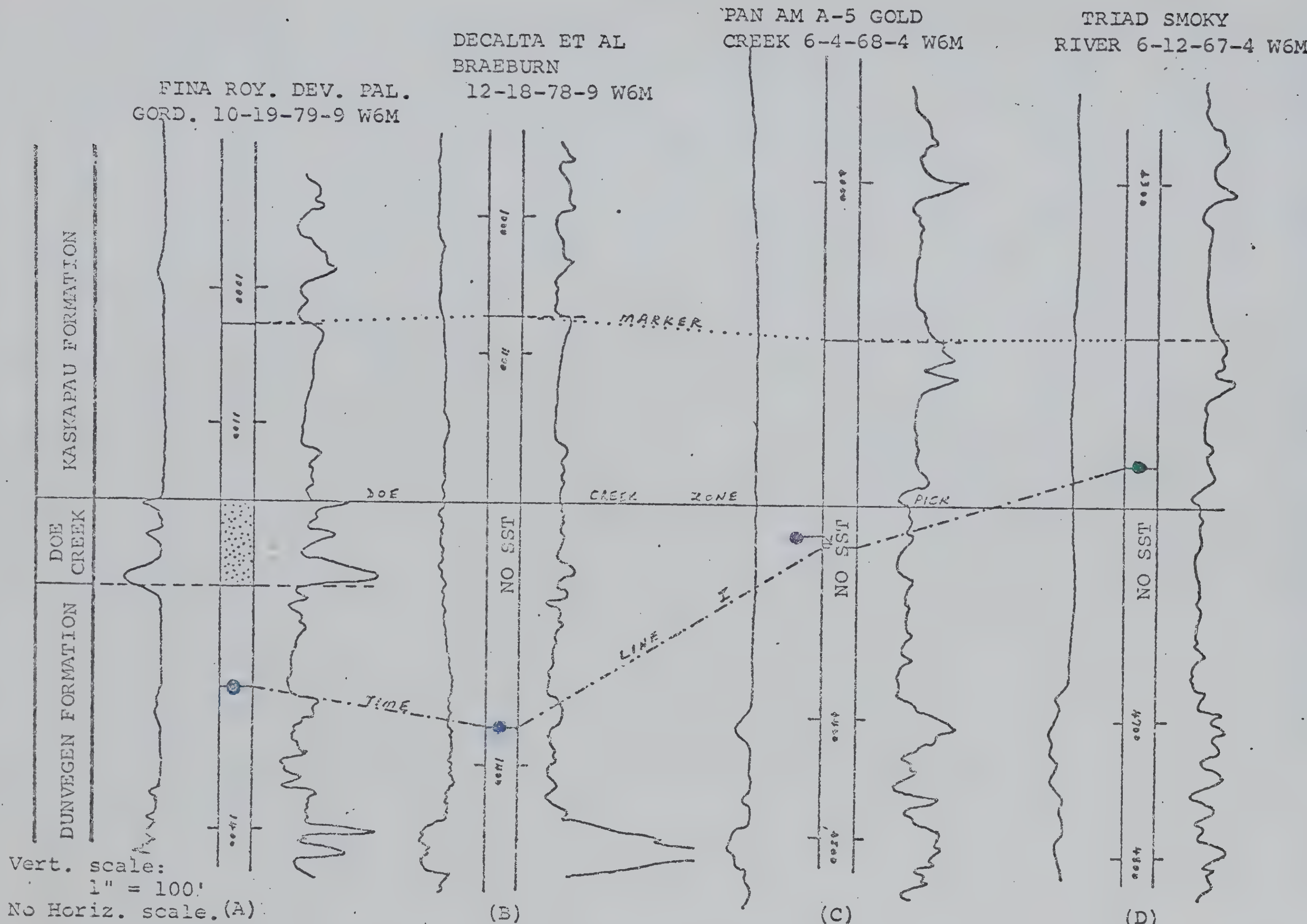


Figure 15. Method of choosing Doe Creek lithofacies. See text for explanation.

sandstone (Map 7) was drawn to accompany Map 1.

DISCUSSION AND INTERPRETATION OF THE LITHOFACIES MAPS

Doe Creek: Map 1.

Due to lack of time, no Doe Creek core was examined. It has been interpreted as one of the last regressive sandstones of the Dunvegan delta complex (Williams and Burk, 1964). In places, it may have formed well developed lithofacies similar to those of the Cardium and Bad Heart. However, because Doe Creek core was neither examined nor interpreted in relation to log characteristics, no paleogeographical lithofacies were mapped for this sandstone.

Instead, the lithofacies were chosen on the basis of presence or absence of sandstone, and then by the position of the time line I intersection on the log relative to the Doe Creek. Sandstone was designated where the spontaneous potential response exceeded an arbitrary cut-off of -5 mv.

Unlike the lithofacies mapped in the Cardium, this method of mapping did not produce a map showing the distribution of paleogeographical lithofacies zones at certain geologic time(s). However, it did produce a lithofacies map, and with the accompanying isopach map (Map 7), paleogeographical interpretations may be suggested.

In the cross section, Figure 13, the Doe Creek lithofacies in the Grande Prairie region appear to be diachronous

relative to time line I along an approximate north-south direction. In Map 1, the lithofacies have been grouped into three broad zones, namely:

Zone 1: lithofacies which were pre-Doe Creek

Zone 2: lithofacies of the Doe Creek

Zone 3: lithofacies which were post-Doe Creek

The zones trend NW - SE, therefore the lithofacies are most strongly diachronous from SW to NE. The relative centre of gravity percentages calculated for zone 1 (Map 1) maintain this trend, showing that Doe Creek deposition was farthest away from occurring towards the NE, in relation to time line I.

In zones 2 and 3 (Map 1), the Doe Creek lithofacies undergoes a facies change from sand in the NW to shale in the SE. This suggests shallowing and possible source area for these these sands towards the NW.

On the other hand, the Doe Creek isopach (Map 7) shows a series of SW - NE trending thicks separated by thins. The thicks could be interpreted as deposits of stream channels which carried sands from a source area probably in the SW, or as bars paralleling depth contours. Without core examination a choice between these interpretations is hazardous.

Cardium and Bad Heart:

Time line mapping produced maps showing the distribution of the lithofacies of the Cardium and Bad Heart Formations at five different approximate times across the area (Maps 2 to 6).

Time II: Map 2:

This time line intersects every well in the marine shales below the Cardium Formation and below any Cardium sandstone. It shows that at time II, the Grande Prairie region was inundated by a vast open marine sea.

Time III: Map 3:

This time line also intersects most wells below the Cardium. However, in the southern portion of the map area, it intersects several wells in the Cardium sandstone, indicative of the beach/barrier lithofacies zone. In one well to the SW, time line III intersects the highly resistive shales of the lagoonal zone.

Therefore, at time III, the initial Cardium sands originating from the uplifted mountains, presumably to the west, began to prograde seaward from the south. The sands were probably deposited as beaches and/or barrier islands, protecting the environment landward. This is indicated by the one well to the SW, which is intersected in the initial

deposits of a restricted bay.

Time line III intersects the C. & E. Saddle Hills 9-28-75-7 W6M well in poorly developed Cardium sandstone lithofacies. It is interpreted to have been a localized development of an offshore bar.

Time IV: Map 4:

Time line IV intersects almost every well in the northern portion of the map area below the Cardium. It intersects most of the wells of the central portion of Map 4 in Cardium sandstone, and nearly every well towards the south in the lagoonal zone.

Therefore, at time IV, a well developed beach/barrier zone, trending roughly NW - SE, had prograded northward halfway across the map area. Extensive lagoonal or restricted bay zone deposits followed. To the north, open marine sediments continued to be deposited, except for some limited offshore bar development around the same location discussed in Map 3.

In the Atlantic Pan Am Nell 12-13-63-2 W6M well to the SE, time line IV intersects the well above the lagoonal zone. This "anomaly" is explained in the following discussion of Map 5.

Time V: Map 5:

This line intersects only a few wells to the NE below the Cardium. Most of the wells in the north were intersected in the Cardium sandstone, indicating that beach/barrier deposition had prograded farther northward. Two lithofacies were plotted for the Cardium sandstone; one symbol designates well developed sandstone, the other indicates sandstone that is rather poorly developed. The distribution of Cardium sandstone maintained an approximate NW - SE trend at time V. The restricted bay or lagoonal lithofacies zone south of the beach/barrier zone approached its maximum extent in time V.

On Map 5 there is an additional lithofacies south of the lagoonal zone. This facies, identified by a different symbol, represents the marine Muskiki muds deposited after the Cardium and prior to the Bad Heart.

It has been shown that the lower contacts of Cretaceous brackish and fresh-water clastic wedges (of which the Cardium is an example) are appreciably diachronous, in response to slow regression of the sea (Russell, 1939; Berven, 1966, p. 210). This has shown up on the lithofacies maps discussed so far. On the other hand, transgressions were relatively rapid, and the upper boundaries of the

wedges are essentially synchronous (Russell, 1939; Fig. 8, p. 97, quoted by Berven, 1966).

In this study, the principle of transgressions being synchronous was not followed when the theoretical time lines were devised. The contact of the upper Cardium Formation with the lowermost Muskiki shales is easily found on most electric logs (Fig. 16). This will be referred to as theoretical time line "omega" (Fig. 17), which differs somewhat from the theoretical time lines calculated on the basis of the First and Second White Specks markers.

If a transgression occurred rapidly across the Grande Prairie region, then time line omega is more accurate than theoretical time line V. A map drawn of the lithofacies just above time line omega would show only the transgressive open marine shales which overlie the Cardium.

For the wells plotted on Map 5, time line V occurs higher and lower than omega, progressing from south to north respectively. Therefore, in the southern part of the map area, time line V intersects many wells in the Muskiki marine shale that overlies the upper Cardium lagoonal facies (Fig. 17).

In Russell's view, the contact of the uppermost Cardium lagoonal muds with the lowermost marine shales

Baysel Regent C. F. P. West
Musreau 10-20-64-5 W6M.

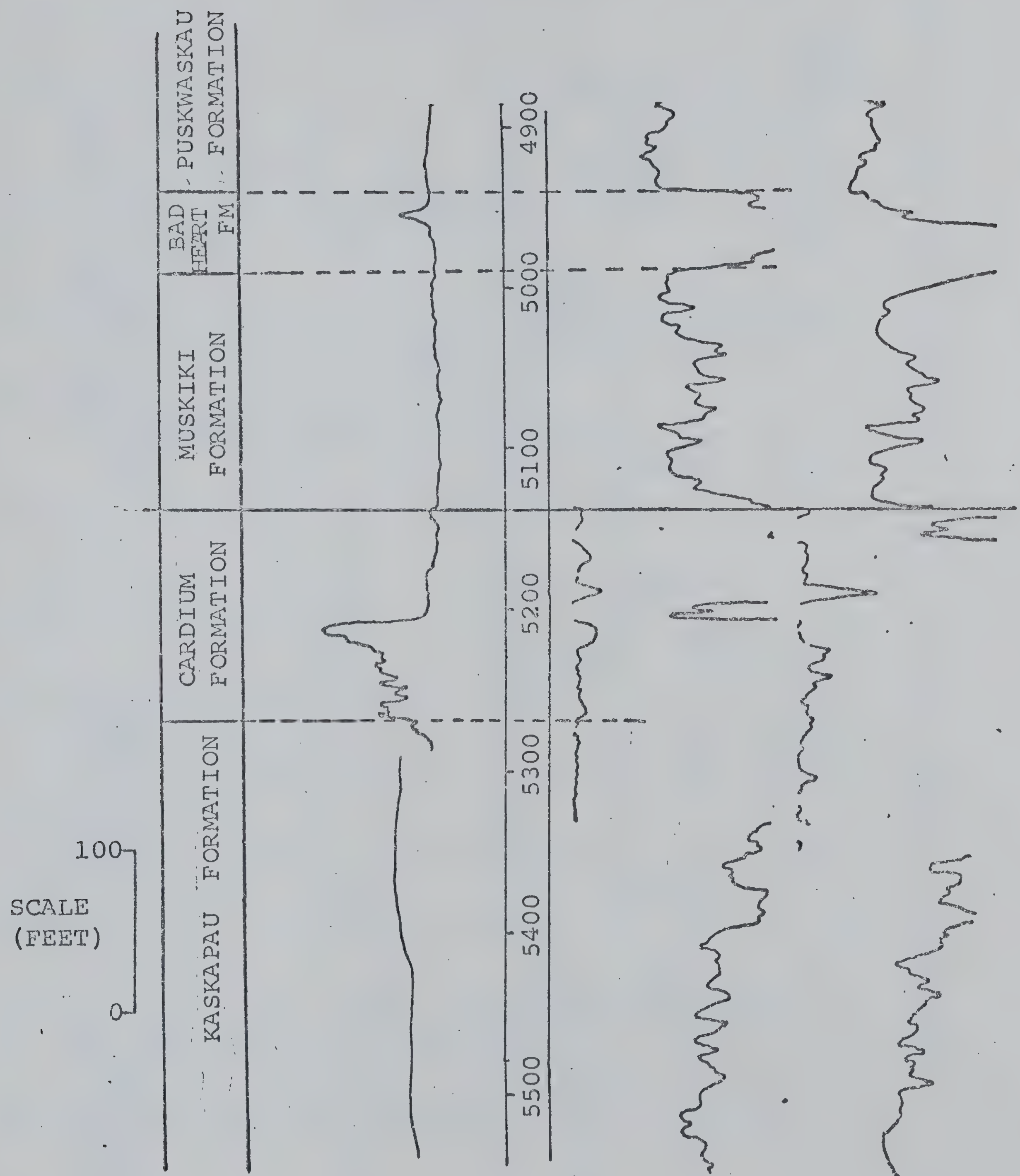


Figure 16. Cardium - Muskiki disconformity.

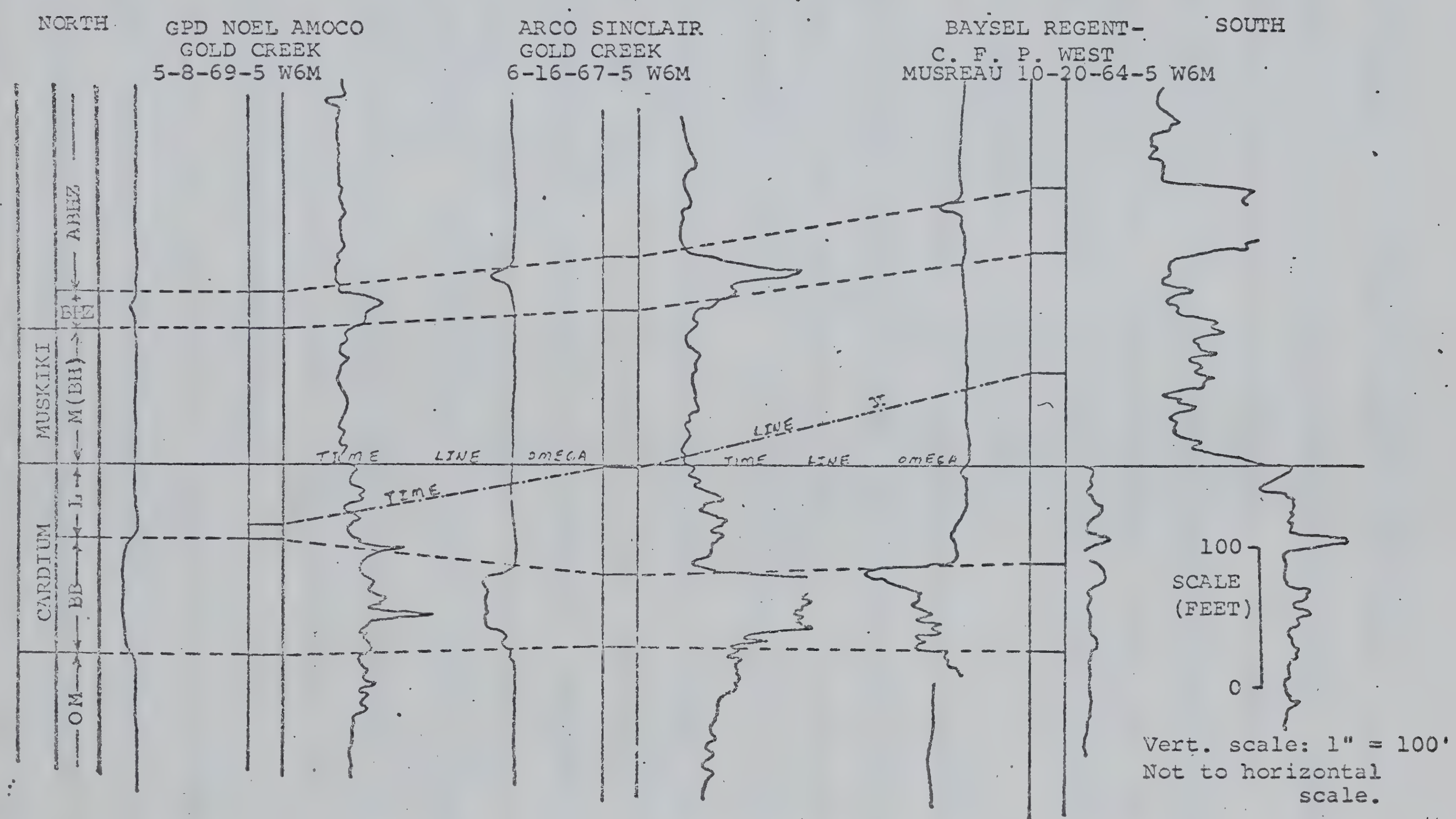


Figure 17. Time line V crosses time line omega progressing from north to south.

of the Muskiki is disconformable. The contact was not examined in cores from the Grande Prairie region. However, it has been described in the foothills: The Muskiki Formation consists of marine shales which lie with slight disconformity on the Cardium Formation. A thin bed of pebbles or conglomerate is commonly present at the base of the shales (Stott, 1961; p. 15).

In the subsurface, a disconformity at the Muskiki - Cardium contact probably occurs, and may be characterized by pebbles or conglomerate which show up as deflections on the spontaneous potential logs in some wells (Fig. 18). The disconformity was probably widespread, although the S. P. logs often fail to reveal it. The disconformity may not always be associated with pebbles or conglomerate, but rather simply have mud (Muskiki) on mud (Cardium lagoonal facies). Even if present, a shale clast or pebble zone may be too thin to be recorded on S. P. logs. In most logs, a noticeable break in the resistivity log usually marks the disconformity.

A true time line would not cross this disconformity. In wells indicated in the southern portion of Map 5, theoretical time line V crosses above the Cardium - Muskiki disconformity, or omega. Therefore, the Muskiki shale litho-

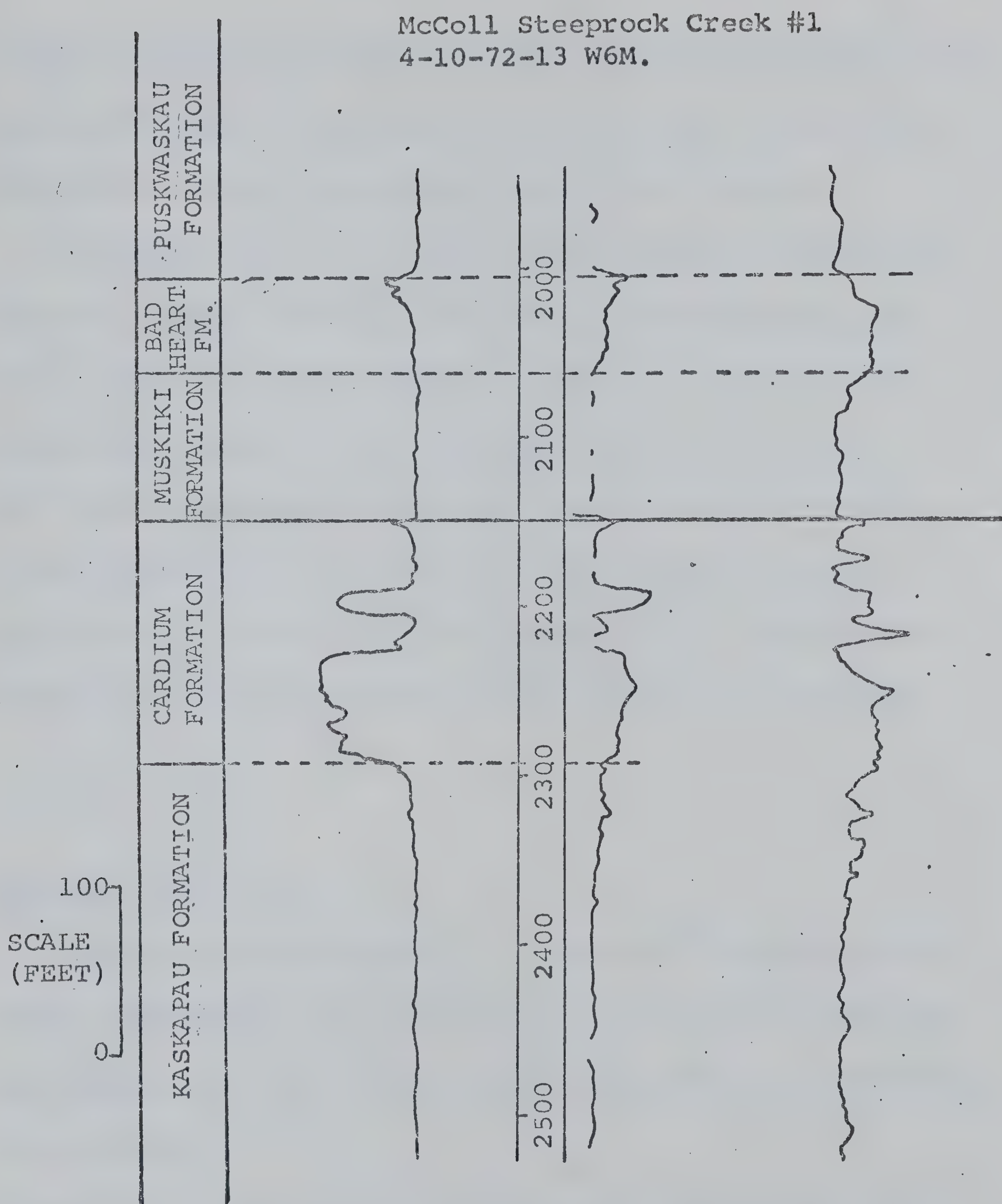


Figure 18. Cardium - Muskiki disconformity, with characteristic S. P. response.

facies as shown represents an area of either non-deposition in Cardium time, or the location of previous lithofacies (Cardium lagoonal lihofacies) since partly removed.

Suppose time line V never intersected the disconformity (or omega), but remained below and roughly parallel to it; then all of the wells south of the beach/barrier lithofacies would show Cardium lagoonal lithofacies. In Map 5 the disconformity makes a considerable discrepancy in the accuracy of time line V, causing Muskiki shale lithofacies, a facies not time-equivalent to the Cardium sandstone, to cover more than one-third of the map area.

Time VI: Map 6:

With a few exceptions, time line VI intersects wells giving lithofacies associated with the Bad Heart Formation. Two exceptions occur due to slight inaccuracy in the choice of time line.

Exception 1: The Cardium beach/barrier lithofacies indicated to the extreme NE of the map area had already been deposited. This was the furthest northern extent of sand progradation mappable in the subsurface; the Cardium was not

found in the subsurface north of township 77 in the Grande Prairie region.

Exception 2: There is an anomalous occurrence of lagoonal deposition, associated with the Cardium, in the Shell Smokey River 6-34-66-4 W6M and Arco Sinclair Gold Creek 6-36-66-4 W6M wells. This arises because time line VI intersects the two wells just below, rather than above the Muskiki - Cardium disconformity, and is therefore a manifestation of the same problem discussed in Map 5.

At time VI, a NW - SE trending zone of Bad Heart sediments had prograded across part of the Grande Prairie region. Bad Heart sandstone is indicated on Map 6 where time line VI intersects the Bad Heart zone in wells having corresponding appreciable negative response of the S. P. log. It was found that development of sandstone litho-facies in the Bad Heart occurred in only about one-third of the wells in this zone. The Bad Heart sands, then, were more poorly developed than those of the Cardium, and may have been deposited as inefficient offshore bars which were periodically destroyed by changing conditions.

Landward, in wells where the Bad Heart sandstone was well developed, there probably followed a zone of lagoonal

facies, similar to that found in the Cardium. This is characterized on some logs by high resistivity, probably indicative of carbonaceous content in the muds (Fig. 19-a). Where the sandstone was not as well developed, the logs do not seem to indicate lagoonal facies (Fig. 19-b), and therefore it is likely that the area landward of the poorly developed bars was fairly unrestricted and remained essentially open marine. Not enough Bad Heart core was examined in relation to the logs to justify interpretation of detailed facies from them. For this reason, the lithofacies of the Bad Heart Formation were based simply on the presence or absence of sandstone, as explained earlier in Table 2.

In the southeastern portion of the map area, another lithofacies is found (Map 6). This indicates wells where time line VI intersects the logs just above the Bad Heart zone. This means that in these wells, by time VI, Bad Heart deposition had already been completed.

Union Nose Creek
14-7-63-11 W6M

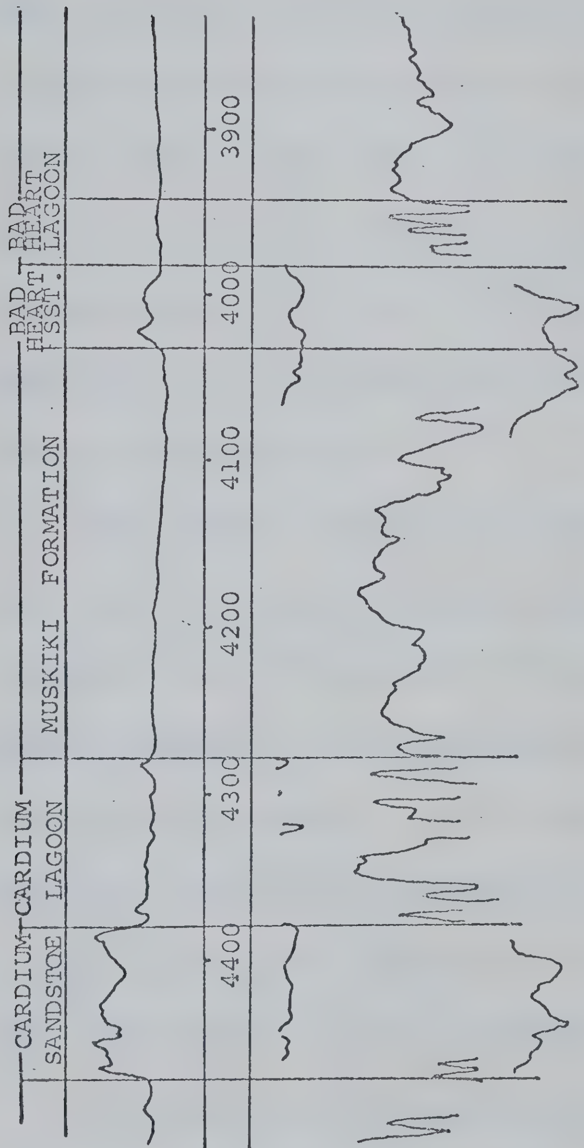


Figure 19-a.
Development of possible Bad Heart lagoonal lithofacies associated with well developed Bad Heart sandstone.

B. A. Musreau Lake
12-20-63-4 W6M

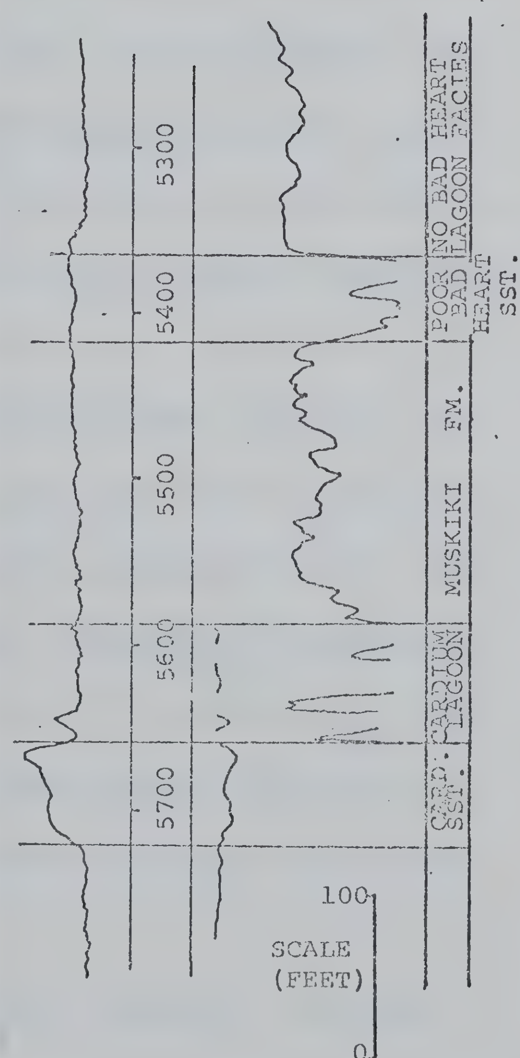


Figure 19-b.
Apparent lack of development of Bad Heart lagoonal lithofacies.

<u>Chinook</u>: Map 8.

Chinook sandstone examined from core in the Bailey Selburn-Regent-C. F. P. Trail 15-30-64-9 W6M well is similar to the Cardium and Bad Heart. It consists of interlaminated and burrowed silty shale at the base, grading upwards into tabular laminated sandstone, then becoming slightly carbonaceous towards the top. It differs from the Cardium and Bad Heart in that it is very glauconitic and contains some thin beds of conglomerate.

An isopach map is drawn of the Chinook sandstone (Map 8). It is possible to pick a Chinook zone from resistivity logs, but for the purpose of isopach mapping sandstone is picked from S. P. curves only where deflections exceed an arbitrary cut-off of - 5mv. Most of the sandstone is distributed sporadically towards the west of the map area, giving the eastward extent of Chinook sandstone migration into the Grande Prairie region.

The Chinook is not found in the subsurface on logs north of the line shown on Map 8.

The Chinook sandstone is the last Smoky River Group regressive deposit, being deposited in association with tectonism in the Cordillera in the late Santonian as shoreline conditions migrated eastward across the present foothills position.

SUMMARY

Throughout Late Cretaceous time the Grande Prairie region was occupied by a broad, epeiric sea, periodically subjected to influxes of terrigenous clastics originating from an area of uplift then carried in by streams from the SW. The first sand to be deposited belonging to the Smoky River Group is the Doe Creek. It originated to the SW and migrated northeastward across the area as a NW - SE trending zone. When conditions changed, the marine Kaskapau shales were deposited as the sea transgressed across the area.

With shallowing during the late Turonian, terrigenous clastics of the Cardium Formation were deposited. Detailed core examination and interpretation of the Cardium showed it to be a regressive sequence, grading bottom to top from open marine and lower shoreface shales and silty shales, to massive middle shoreface and tabular laminated upper shoreface sands, through to carbonaceous lagoonal or restricted bay mudstones, interrupted occasionally by cross-laminated channel sandstones.

With renewed subsidence during Coniacian time, the Cardium lithofacies were overlain by marine Muskiki shales. Later, the sea began to shallow once more with the onset of deposition of the Bad Heart sandstone. The Bad Heart,

examined in a few cores, appears to grade from marine at the base to non-marine towards the top, but has not developed the various easily recognized lithofacies seen in the Cardium.

Mapping the Cardium and Bad Heart sandstones regionally over the map area involved using theoretical time lines calculated for each well on the basis of given distances between the First and Second White Specks markers. Most of the lithofacies were determined from log characteristics which had been correlated with several examined cored intervals. Maps were produced which showed the position of the Cardium and Bad Heart lithofacies at five different approximate times across the Grande Prairie region.

At time II the area was inundated by a vast open marine sea. By time III, a zone of Cardium beach/barrier lithofacies began to prograde northward originating from the southern part of the map area. A well developed beach or barrier island zone trending NW - SE, had migrated halfway across the map area by time IV.

The shoreline had moved farther northeastward in time V, leaving an extensive lagoon behind, and to the south of this, an area indicated as Muskiki shale facies. This

shale is not time-equivalent to the Cardium sandstone, but the area so designated represents a zone of either non-deposition in Cardium time, or the location of previous Cardium non-marine lithofacies, since partially removed by the marine transgression of the Muskiki.

By time VI, the Bad Heart sandstone had prograded as a NW - SE trending zone across about half of the map area. The Bad Heart zone having well developed sandstone occurs in only one-third of the wells, possibly indicating rather inefficiently developed beaches and/or barriers.

The water deepened somewhat after deposition of the Bad Heart, followed by deposition of the Puskwaskau shale during late Coniacian and early Santonian time.

Onset of tectonism in the Cordillera in the late Santonian produced the Chinook sandstone found in the subsurface along the western edge of the Grande Prairie region.

REFERENCES

Berven, R. J., 1966: Cardium sandstone bodies, Crossfield-Garrington area, Alberta; Bull. Can. Petrol. Geol., vol. 14, No. 2, pp. 208-240.

Burk, C. F., Jr., 1963: Structure, isopach, and facies maps of Upper Cretaceous marine succession, west - central Alberta and adjacent British Columbia; Geol. Surv. Can., Paper 62 - 31.

Davies, D. K., Ethridge, F. G., and Berg, R. R., 1971: Recognition of barrier environments; Am. Assoc. Petroleum Geologists Bull., v.55, no. 4, p. 550-565.

Krumbein, W. C., and Sloss, L. L., 1963: Stratigraphy and Sedimentation, 2nd edition, W. H. Freeman and Company, San Fransisco, California.

McLearn, F. H., 1919: Cretaceous, lower Smoky River, Alberta: Canada, Geol. Survey, Summ. Rept. 1918, pt. C. p. 1-7.

Michaelis, E. R., and Dixon, G., 1969: Interpretation of depositional processes from sedimentary structure in the Cardium sand; Bull. Can. Petrol. Geol., v. 17, no. 4, p. 410.

Park, J. M., 1965: Biostratigraphy of the Upper Cretaceous White Speckled Shales in Central Saskatchewan; University of Saskatchewan, M. Sc. Thesis.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1965: Geology of Sand and Sandstone, Chapter 13, p. 173-197.

Russell, L. S., 1939: Land and sea movements in the Late Cretaceous of Western Canada: Trans. Royal Soc., Canada, 3rd ser., sec. 4, v. 33, p. 81-98.

Sinha, R. N. 1970: Cardium Formation, Edson Area, Alberta; Geol. Surv., Canada, Paper 68 - 30.

Stott, D. F., 1961: Summary account of the Cretaceous Alberta Group and equivalent rocks, Rocky Mountain Foothills, Alberta; Geol. Surv., Canada, Paper 61-2.

Wall, J. H., 1960: Upper Cretaceous Foraminifera from the Smoky River Area, Alberta; Alta. Res. Council, Bull. 6.

Warren, P. S., and Stelck, C.R., 1940: Cenomanian and Turonian Faunas in the Pounce Coupe District, Alberta and British Columbia; Trans. Roy. Soc. Can., 3rd ser., sec. 4, v. 34, pp. 143-153.

Williams, G. D., and Burk, C. F., Jr., 1964: Upper Cretaceous (Chapter 12); Geological History of Western Canada, (Ed. R. G. McCrossan and R. P. Glaister), Alta. Soc. Petrol. Geol., Calgary, 232 p.